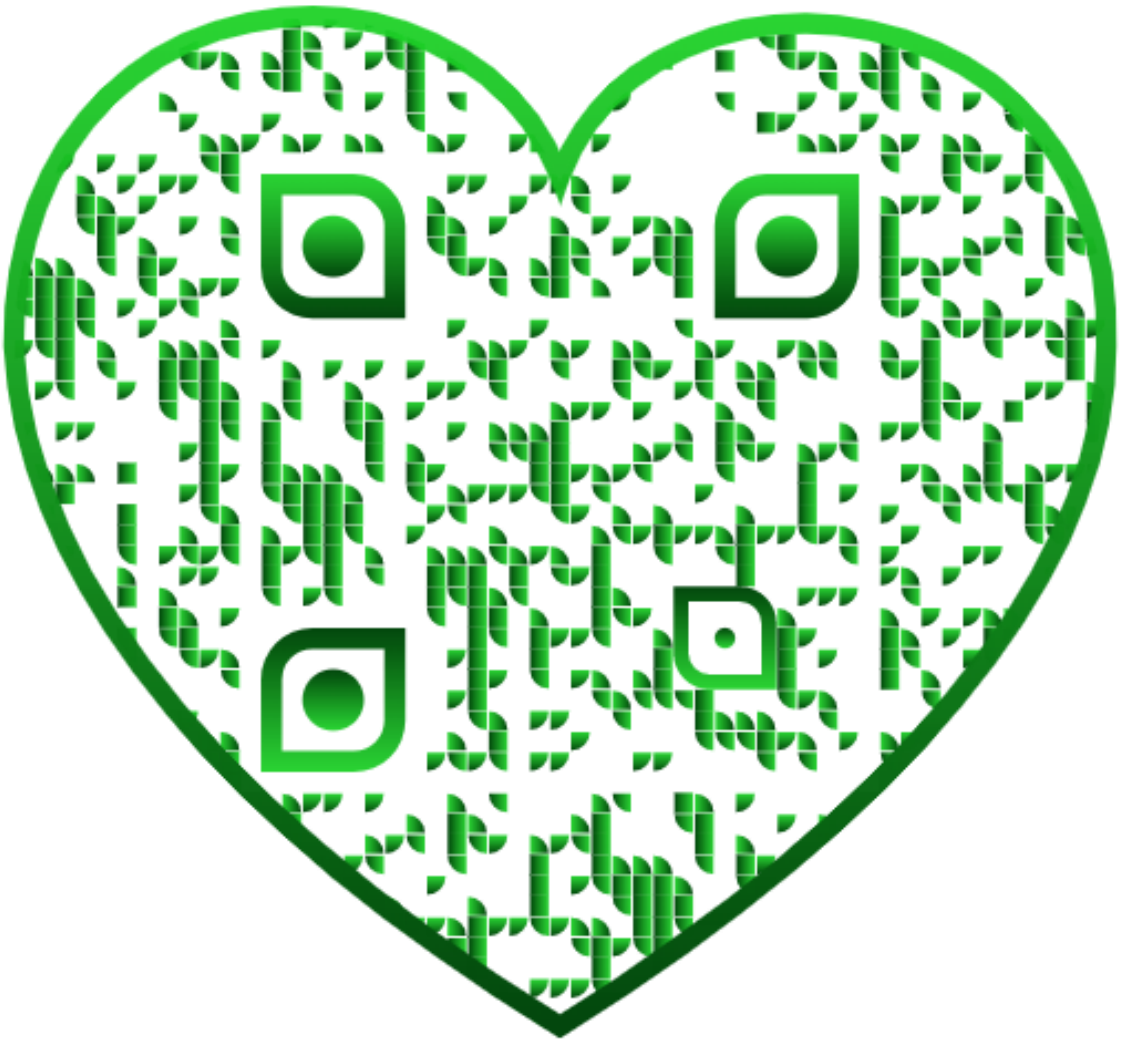
'A magnificent accomplishment'
PROFESSOR MARCIA LANGTON

The First Astronomers

How Indigenous Elders read the stars

DUANE HAMACHER
WITH ELDERS AND KNOWLEDGE HOLDERS



All royalties for The First Astronomers *will go to charities supporting First Nations projects and people in astronomy.*

About the authors

Duane Hamacher is Associate Professor of Cultural Astronomy in the School of Physics at the University of Melbourne. He earned graduate degrees in astrophysics and the social sciences and has appeared on TEDx, *The Story of God with Morgan Freeman*, and many other high-profile local and international programs. He serves as an expert consultant for UNESCO and works for Elders in the Torres Strait and around the world to document traditional star knowledge for educational programs and public understanding.

Ghillar Michael Anderson is a Senior Law Man and leader of the Euahlayi Nation in New South Wales, Australia. **Ron Day, Segar Passi** and **Alo Tapim** OAM are all Elders from Mer in the eastern Torres Strait, Australia. **David Bosun** is an artist and Knowledge Holder from Mua in the western Torres Strait. The late **John Barsa** was a Knowledge Holder and Meriam astronomy expert from Mer.

The First Astronomers website:

www.thefirstastronomers.com

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RON DAY
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ALO TAPIM

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Contents

Foreword: Professor Marcia Langton

Prologue

1 Star Knowledge

2 The Nearest Star

3 The Moon

4 The Wandering Stars

5 The Twinkling Stars

6 The Seasonal Stars

7 The Variable Stars

8 The Cataclysmic Stars

9 The Navigational Stars

10 The Falling Stars

Epilogue

Acknowledgements

Glossary of astronomical terms

References

Index

Foreword

By Professor Marcia Langton AO

Like many Aboriginal people of my age, my childhood in rural Queensland was difficult and precarious. But if I remember the best of times, one that stays with me is lying under the night sky and seeing the Milky Way in all its glory—a great blanket of sparkling lights seeming to hover over me. In my adulthood, I took my children travelling across the country to give them this experience. Far from city lights, we joked about the Starlight Motel as we lay in our swags next to a small fire and watched the nightly show of the great river of stars moving slowly over us. We watched the twinkling stars, shooting stars, and pointed out the Southern Cross and other great constellations. Relatives and family friends had wonderful names like Starlight, Sunlight and Moonlight, and I knew that in the skies was a world that my people held and cherished. Now, we must travel further across the country to find dark skies, free from the glow of city lights, to see the stars in all their wonder.

During my own studies of Aboriginal histories and cultures over the last fifty years, I learnt that there are great bodies of knowledge about the sky. When I first met Duane Hamacher, I learnt more about the research and collaborations between Indigenous and Western astronomers. In 2018, I recruited him to join an Expert Panel to advise on the National Aboriginal and Torres Strait Islander Curricula Project. Our first goal was to develop resources for classrooms on Indigenous Knowledge under the themes of *fire*, *water* and *astronomy*. Now all Australian teachers are able to bring Indigenous astronomy to their classrooms, assured of the rigour and authenticity of the information we freely provide so that every child can learn about the great legacy of our ancient and living knowledge systems.

Between the covers of this extraordinary book is a detailed account of the science behind Indigenous star knowledge, presented by Duane and guided by six Indigenous Elders and Knowledge Holders: Ghillar Michael Anderson,

John Barsa, David Bosun, Ron Day, Segar Passi and Alo Tapim. Rarely is a book of such importance published. When profound ideas are introduced to the world for the first time, our world is fundamentally changed and the previous understandings consigned to history. There are those who continue to deny the intelligence and scientific traditions of Indigenous people. The idea that the only *true* science is that of Western thinking must be consigned to history. Those who read this book will understand why.

The First Astronomers is so much more than academic salvaging of past traditions. This is an account of historical and living Indigenous sky knowledges that are passed down through poetic narratives about the great ancestors who made the world. The power of oral traditions is evident in this book, with knowledge of sky phenomena remembered over hundreds of generations or deduced with the finely honed observational and analytical skills. To so elegantly bring together astronomical science and Indigenous cultural expressions of the sky in one book is a magnificent accomplishment.

Yet, even more impressive is how these ancient bodies of knowledge are explained by an expert with a great flair for detailing the scientific and academic understandings of Indigenous star knowledge. Duane includes historical, current and scientific accounts of Indigenous and local astronomical knowledge from around the world, giving the book a global scope. Duane's expertise as a Western-trained astrophysicist has been brought to bear in several ways in detailing these extraordinary traditions. He worked with Elders in the Torres Strait over the years, listening and learning, recording their knowledge according to their instructions, and bringing the insights of Western astronomy to find synergies between these knowledge systems.

Indigenous readers like myself will be delighted by examples of our traditions and their applications to the lives of our ancestors, who knew their own countries intimately. Aided by their knowledge of the stars, they could travel thousands of miles across land and sea. Just as fascinating is the research process itself. As a young American student visiting Australia for a semester, Duane was struck by dismissive responses of contempt at the idea that Aboriginal people have worthwhile knowledge of the stars. This experience set him on a path to learn about Indigenous astronomy across Australia and the world.

With students and colleagues from far-flung communities and universities around the globe, he has contributed to a globally renowned body of

academic and scientific literature. This work has flowed across disciplines, enlivening scholarship on Indigenous societies in the humanities and sciences, especially environmental and climate studies. This book marks a profound paradigm shift in our understanding of Indigenous scientific traditions, how they are transmitted, and their relevance to life today.

Significant to understanding the interconnectedness of Indigenous knowledge is recognising the important role of story, song, dance and ceremony. Many dismiss these cultural expressions as *myth* and *legend*, but they are not. *They are interwoven narratives that bring together systems of knowledge*. The interconnectedness of star knowledge with understandings of patterns and phenomena in nature, including seasons, weather, plant and animal behaviour, geology, and even human behaviour, is revealed in each of the accounts provided by Elders herein.

One cannot help but be in awe at the sheer effort that went into this body of work. The knowledge of Elders is a part of the legacy of thousands of generations of people watching the skies and tracking celestial affairs. Oral traditions tell of phenomena that long predate their discovery by Western scientists, such as the variability of stars, a phenomenon long known by Aboriginal peoples but only 'discovered' by Western astronomers in the mid-nineteenth century. This is just one example in this marvellous book that examines the antiquity of Indigenous star knowledge.

It might appear that a Western logic has been applied to Indigenous knowledge here, but this is far from the truth. The fact is that Indigenous astronomers knew about the movements of the Sun, eclipses, sunspots, solstices and the seasons in enormous detail through daily observations, remembered in oral traditions preserved in narratives, songs, designs and dances. They understood the phases of the Moon, the cause of eclipses, sounds associated with aurorae, and so much more. Each chapter is organised around these concepts as they are understood in Indigenous scientific traditions.

The First Astronomers will help readers value the complex layers of scientific information in Indigenous knowledge of the stars, and how this living legacy is still important today. These ways of knowing have inherent value and are leading Western scientists to better understand celestial phenomena and the history and heritage this constitutes for all people. We all inherit this ancient knowledge but only if we respect it. The great challenge is to ensure that the Indigenous people have the opportunity to transmit it to

future generations. I hope this book brings a new generation of Indigenous astronomers to the task of preserving, documenting and sustaining this bequest from the ancestors to learn from their knowledge of the sky.

Prologue

'We came here as spirits from Star Nation. When we get done with this life, we make that sacred journey back to the stars on the path of the Milky Way—the Wanáği Thacháŋku.'

—Arvol Looking Horse, Lakota Elder and spiritual leader

The First Astronomers challenges commonly held views that Indigenous ways of knowing do not contain science. It showcases the deep layers of star knowledge that are based on observation, deduction, experimentation and collective wisdom that provides insights and solutions to some of the problems we face today. *The First Astronomers* is a book ten years in the making through ongoing collaborations with Elders and communities who wanted to share their knowledge with the public.

Those who contributed most significantly are included as authors with their approval. Although much of this information was published in the academic scholarship, some of the content in this book has never been published. Exciting and important new details were shared by Elders even as I wrote the manuscript.

The First Astronomers also includes critical reflections on research drawn from publications by largely non-Indigenous scholars and writers. The academic scholarship is filled with 'research findings' about First Peoples that are riddled with errors, conflations and biases. Part of that is simply the process of scholarship, and I have not been immune to this in my own work. In other cases, errors come from a lack of knowledge about positional astronomy and celestial mechanics. Still others have occurred due to colonial practices aimed at achieving an outcome that rarely benefited the people or their communities.

I wrote the book itself, but it has been guided by the Elders and Knowledge Holders, who wanted to share the complexity, depth and significance of their traditional star knowledge with the world. We have linked the people to their knowledge wherever possible. In some cases, the people who shared knowledge are not named as they chose to remain anonymous; however, these interviews have been documented and the records shared with the

Elders, as well as their representative organisations. In some cases, protocols prevented Elders from being specifically associated with the knowledge they have provided.

Elders and Knowledge Holders are authors on many of the papers referenced in this book, some of which include titles and abstracts in both English and the traditional language. They are the main consultants for the outcomes and applications of the research findings, and they guide the outcomes that drive this process.

Many readers will notice that the Elders and Knowledge Holders included as authors are men. This is due to the protocols set out by the different communities. Access to traditional knowledge is also guided by initiation or levels of seniority. On one occasion, I sat down with four Elders on Mer in the eastern Torres Strait after I presented the community with a new telescope. When I asked a question about traditional astronomy, three of them simultaneously looked over to Uncle Segar Passi, the senior Elder, and awaited his response. Most of the knowledge shared in this book is what might be considered the 'lower levels', meaning it is equivalent to primary school in traditional cultures. Star knowledge is far more complex and in-depth than we discuss in this book, but even this is a lot to absorb.

All the knowledge provided by Elders in this book has been approved for public eyes. Higher, secret levels of knowledge exist, but they are not presented here. On a few occasions I have been wrapping up interviews with Elders, and just as I was about to leave the Elder quickly dived into the 'true depths' of this knowledge. This came too quickly for me to absorb but was never meant for me to remember or record. It was for me to understand that what they were sharing was only the tip of the iceberg. These experiences always ended with a sly smile from the Elder and an acknowledgement from me that despite my excitement and enthusiasm, I was nowhere near having the full details. Knowledge is power, and sharing that knowledge is part of a process of building trust and rapport. As the years passed, Elders gradually taught me more and more, but always with the clear understanding that they guided what was to be shared publicly.

Who we are

> 'My nan and pop were always talking about the stars and they'd tell you all the different stories. We have a lot to teach the rest of the world. Thank goodness our old people left a lot of knowledge behind for us to pass on to our generations. I think the world would benefit a lot from

it.’

—Ghillar Michael Anderson

Traditional star knowledge is passed down through family and community, and the six Elders and Knowledge Holders listed as authors shared the deepest layers of that knowledge: Ghillar Michael Anderson, John Barsa, David Bosun, Ron Day, Segar Passi and Alo Tapim. Each has published research on Indigenous astronomy in scientific journals and are all keen to share this knowledge for the benefit of future generations.

Ghillar Michael Anderson (b. 1951) is an Aboriginal activist, academic and Senior Law Man from Goodooga, New South Wales. He is a leader of the Euahlayi Nation, and one of the co-founders of the Aboriginal Tent Embassy in 1972. Uncle Ghillar appeared on *Stargazing Live* in 2017 and the 2018 documentary *Star Stories of the Dreaming*.

Segar Passi (b. 1942) is a Dauareb man and senior Elder on Mer, an island in the eastern Torres Strait. He is a nationally renowned award-winning famous artist who started his painting practice in the 1960s. His paintings focus largely on natural and cultural scenes, such as the local land- and seascape, clouds and animals.

John Barsa (1963–2018) was a Magaram man from Mer, a master craftsman whose craft focused on weaving, carving and *dhari* (traditional headdress) making. His knowledge of traditional astronomy was unparalleled, and he shared some of the deepest levels of star knowledge in the community.

David Bosun (b. 1973) is a Mualgal man, printmaker, woodcarver and senior artist at Moa Arts. He is one of the founders of the printmaking tradition in the Torres Strait. Uncle David earned a degree in communications and a Diploma of Visual Art and served as a local councillor.

Ron Day (b. 1953) is a Komet man and Elder on Mer. Uncle Ron is a priest and served as a community leader and Chair of the Mer Island Council for over fifteen years. He is highly respected for his deep cultural knowledge, particularly about the stars.

Alo Tapim (b. 1946) is a Dauareb man and Elder on Mer. Uncle Alo studied linguistics at the Batchelor Institute and serves on the Cultural Committee in the Torres Shire Council. He appeared in the 1978 TV series *Castaways* and the 2020 film *Fireball*. Uncle Alo was awarded a Medal of

the Order of Australia (OAM) in 2020.

I'm originally from the rural farmlands of the American Midwest. As a child, I grew up with a passion for astronomy. I was also swept up in the Australian frenzy that hit the United States in the 1980s with Men at Work's radio hit and the success of *Crocodile Dundee*. But it was a kid's action film called *The Quest* in the United States (*Frog Dreaming* in Australia) that heavily influenced me. Moving 'Down Under' became a lifelong goal, albeit one that seemed a distant dream.

By my mid-twenties I found myself in Sydney for a semester as a Study Abroad student at Macquarie University. It was August 2003 and Mars had reached its closest approach to the Earth in almost 60,000 years. During a telescope viewing at the campus observatory, I casually asked someone about the astronomical knowledge of Aboriginal people. Their response was disgusting and dismissive. I didn't know it at the time, but that shocking experience would change my life and put me on the path to writing this book nearly twenty years later.

That semester in Australia was an otherwise amazing experience. I went back to the States and completed my degree in physics at the University of Missouri, with a focus on astronomy. I also completed several undergrad and graduate courses in anthropology and archaeology. My dream of returning to Oz came to fruition when I was accepted into the PhD program at the University of New South Wales (UNSW) in Sydney. Despite the excitement of searching for planets orbiting distant stars, my mind constantly wandered back to that experience I had at Macquarie a few years earlier.

Although I knew next to nothing about Aboriginal cultures or history, it seemed obvious that people who have been around for tens of thousands of years would know a thing or two about the stars. A cursory look confirmed this. Not only that, it was crystal clear this knowledge contained a lot of scientific observations and discoveries that were not recognised or acknowledged by Western science. I decided to write up my exoplanet research for a master's degree and set out to pursue a PhD to learn more about Aboriginal astronomy.

I was accepted into a doctoral program in the Department of Indigenous Studies at Macquarie University in 2008. I was back where it all began and loved the highly interdisciplinary nature of the work. My program was supervised by an anthropologist, an astrophysicist, an archaeologist and an Aboriginal educationalist. I also experienced a dramatic shift in my

worldviews and became increasingly aware of my own cultural baggage. The relief I felt from letting it go was exhilarating.

In early 2009 I was introduced to Uncle Les Bursill, a Dharawal Elder. Uncle Les completed bachelor's and master's degrees in anthropology and archaeology, and one of his primary interests was rock art. He became my mentor, teaching me about Aboriginal culture and history, taking me to dozens of rock art sites across southern Sydney, explaining their meanings and pointing out how they connect to the land, sea and sky, and to other communities through ceremony.

Uncle Les was extremely supportive, and we collaborated over the years. In 2014 he began working closely with Bob Fuller, who completed a PhD under my supervision at UNSW on the astronomy and Songline connections of saltwater Aboriginal communities of coastal New South Wales. I was fortunate to visit Uncle Les the day before he passed in early 2019, and he was excited about *The First Astronomers* being published. Bob's research with Uncle Les is now being published posthumously with the Elder as an author, with permission from his family. He is one of the two people to whom this book is specifically dedicated.

The First Astronomers is the outcome of a process set in motion nearly ten years ago, when Professor Martin Nakata sat with me and laid out the roadmap for the future of Indigenous astronomy scholarship, and it is a book that I am deeply honoured to write under the guidance of Elders.

To honour this process, all proceeds of this book will go to charity to fund scholarships, research programs and community projects for First Peoples.

Duane Hamacher

September 2021

CHAPTER 1

Star Knowledge

‘Our traditions around the stars go back to ancient times. It’s connected to everything in our entire being and who we are in the world. For Indigenous people, it’s not just the land and the sea. It’s also the sky and in using those reference points. It assigns not just who we are, but our responsibilities as well.’

—Professor Martin Nakata

It was 2011 and Martin Nakata was riding a camel in the Gobi Desert with Curtis Wong, the head of Microsoft Research. Professor Nakata was the first Torres Strait Islander to earn a doctorate in Australia and is an expert on the intersection of Indigenous and Western ways of knowing. At the time he was the director of the Nura Gili Centre for Indigenous Programs at the University of New South Wales in Sydney. The two shared their mutual love of the stars and began discussing exciting innovations that could be realised by joining traditional systems of knowledge with modern technology. This reignited Professor Nakata’s lifelong passion for astronomy and the pair decided to act on their idea. They formulated a project outline, secured funding, and all systems were go.

Then they hit a roadblock. For all their enthusiasm, neither of them had any formal training in astronomy. What they needed was someone who had qualifications in astrophysics, but also was familiar with Indigenous astronomy. This is not a common skillset and the odds of finding someone seemed slim. When Professor Nakata searched online, my name kept popping up. I had the qualifications and track record he was seeking, so he sent me an email asking if I wanted to meet.

When I opened the email, I was excited as I had read about his work. At the time, I was trying to carve out an academic pathway so I jumped at the opportunity. We met at a Thai restaurant near the UNSW campus with a couple of Nura Gili staff members. The professor seemed taken aback by my

country-fried accent. I don't think he was expecting an American from the rural Midwest. After a long and lively chat, he asked if I wanted a job. This was the beginning of an ongoing collaboration that would lead to outcomes I never anticipated.

Professor Nakata and I planned a major project to work with Elders in the Torres Strait, an archipelago of islands between Papua New Guinea and Cape York at the north-eastern tip of the Australian mainland. The project set out to capture and document traditional star knowledge for the benefit of the community. This would enable the Elders to share *their* knowledge on *their* terms, and do so as collaborators, not 'research subjects'. The Elders guided the outcomes and decided how they should be applied.

The Torres Strait comprises five major island groups, each with a unique geography. The Islanders are culturally Melanesian, but with close links to Aboriginal communities on the mainland and in the south-western island group. Two major languages are spoken: Kala Lagau Ya (and various dialects), a Pama–Nyungan Aboriginal language spoken in the western and central islands, and Meriam Mir, a Papuan language spoken in the eastern islands. Today, a majority of Islanders speak English and Yumplatok (Creole).

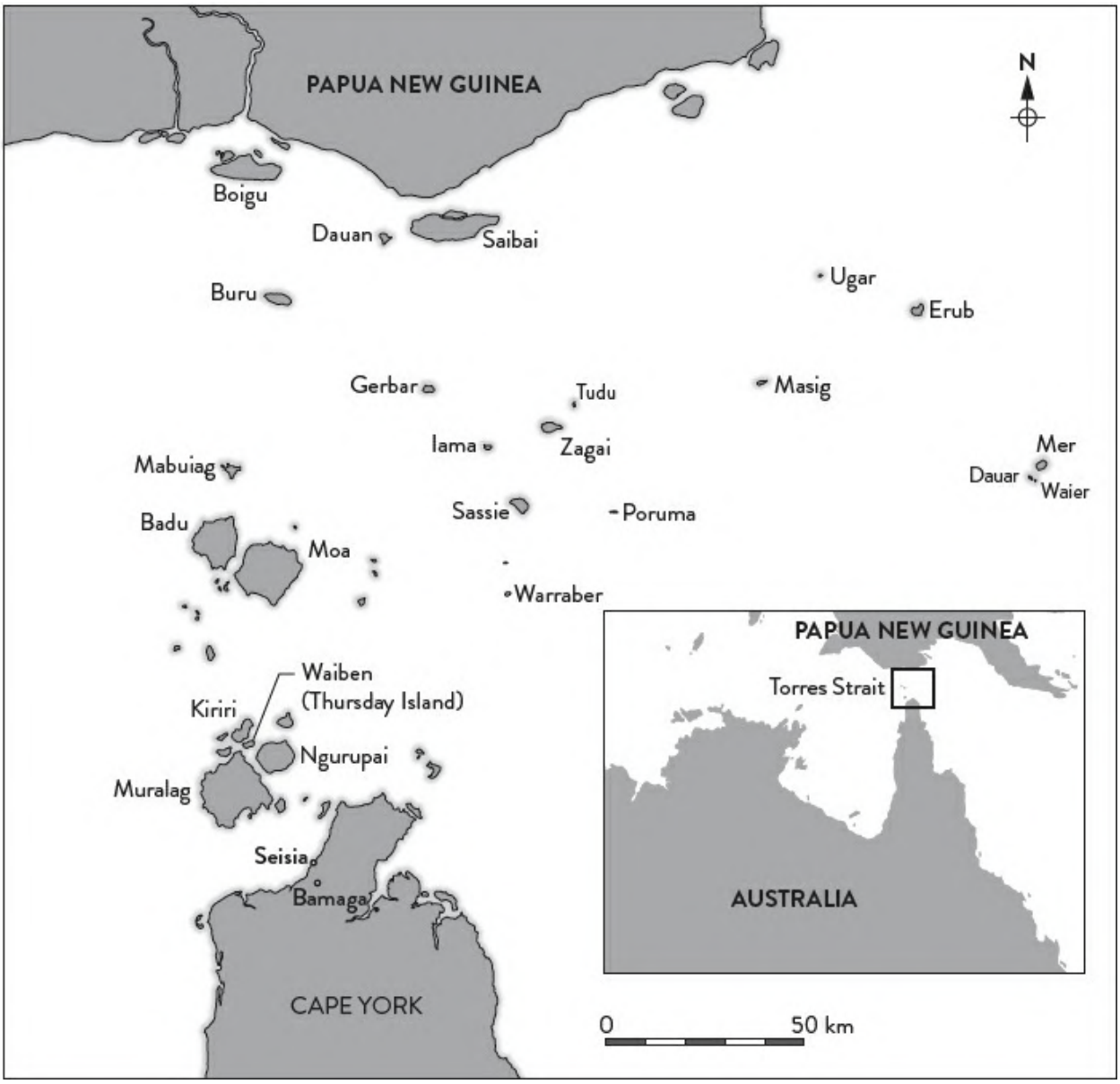
It is a place where traditional culture is rich and thriving yet is under constant pressure from limited economic opportunities and the ongoing effects of colonisation that slowly erode traditional ways of knowing and living. Fluent speakers of the traditional languages are decreasing in number, and with that, ancient knowledges are slowly evaporating. This is why Elders want their knowledge recorded and developed into education programs for future generations.

In 2014, I was awarded a fellowship from the Australian Research Council and I set off to the Straits for my first trip with Professor Nakata. The experience was eye-opening. We stayed the first night on Waiben (Thursday Island). That evening, we were sitting in the glow of a half Moon when I recognised a familiar pattern in the stars. I pointed northward and said those were the stars of what I grew up calling the Big Dipper, part of the Western constellation Ursa Major. I had read that these same stars, although 'upside down' to my northern hemisphere-conditioned mind, were regarded as a shark in the Straits. The professor nodded. I said that when the nose of the shark touches the horizon at sunset, it is supposed to signify that sharks are breeding and are considered dangerous as they swim close to shore. 'Is this

right?’ I asked.

He smiled. ‘Wait till tomorrow.’

The next day we flew to Mer (Murray Island), in the far eastern Torres Strait. It’s a small volcanic island, just a bit over 4 square kilometres in area. A couple of kilometres to the south-west are the small islands, Dauar and Waier. We got off the plane, walked down to the lodge, dropped off our gear and strolled down to the beach. As we stood near the waves, my jaw dropped. Sharks were darting back and forth just metres from the shore, in knee-deep water. They were feeding on *tup*, the Meriam term for sardines. I looked at the professor and he nodded. My curiosity was piqued.



‘I can see why it’s so dangerous to be in the water right now, but when the plane was landing, I saw a group of kids swimming near a dock. Aren’t they worried about getting bitten?’

He looked off in the distance and took a deep breath. ‘Nah … we train them to only bite whitefellas.’

I nearly spit my water out when he said that.

This was a golden opportunity to see traditional knowledge in action. It is one thing to read about how people link the positions of stars to the behaviours of animals, but another to see it firsthand. The professor then emphasised: ‘Always remember, we are a people of culture. We are also a people of science. You’re here because you’re a scientist. No matter what others say, don’t forget that and don’t ever lose your sense of scientific integrity. If that happens, it’s all over.’

That evening, we walked along the beach until Dauar and Waier came into view. The Sun had just set, and the glow of the western horizon put the islands in silhouette. Dauar is only half a square kilometre in area, with two hills and a long, narrow peninsula extending to the north-west. Every landmark on the island has a story behind it, and many of them include the stars. Some of the Elders lived on Dauar as children but were relocated when the government moved the community over to Mer in the 1950s. The professor gestured in the island’s direction. ‘That place is powerful. Those Elders have deep knowledge. They’re the big dogs. If you want to learn about the stars, you start with them.’

My journey into the world of Indigenous star knowledge, and the deep layers of scientific knowledge that are embedded within it, began on this tiny remote island at the tip of the Great Barrier Reef. The Elders I met here feature heavily in this book, along with many more across the Torres Strait and in wider Australia, and around the globe.

People of science

Professor Nakata’s statement about Aboriginal and Torres Strait Islander people being people of science conflicts with the mainstream view that science is a product of Western philosophy. It *is*—it is just not *exclusively* so. Throughout human history, cultures across the world have developed and

applied their own forms of science. They are not all the same, but they share a similar goal of understanding the world through empirical observation, experimentation and collected knowledge. As Professor Rangi Mātāmua, a Māori astronomy scholar, explains:

> Look at what our ancestors did to navigate here—you don't do that on myths and legends, you do that on science. I think there is empirical science embedded within traditional Māori knowledge … but what they did to make it meaningful and have purpose is they encompassed it within cultural narratives and spirituality and belief systems, so it wasn't just seen as this clinical part of society that was devoid of any other connection to our world, it was included into everything. To me, that cultural element gives our science a completely new and deep and rich layer of meaning.

Dr Annette S. Lee is a First Nations Lakota woman, astrophysicist and professional artist from Minnesota in the United States. She earned degrees in art and science from Berkeley, Yale and other top-tier universities, and her PhD and Master of Fine Arts theses focused on Indigenous astronomy topics. She is also the Director of Native Skywatchers, a research and education initiative that focuses on remembering and revitalising Indigenous star knowledge. She argues that:

> Science is something anyone can do, and everyone has done. The process on paper is simple: closely observe the world, test what you learn, and transmit it to future generations. Just because Indigenous cultures have done this without test tubes doesn't make them unscientific—just different.

Indigenous Knowledge demonstrates that science can be understood to have a much broader scope than what is usually considered to be Western science. These scientific traditions are much older than Western science and were developed independently of it. More importantly, they demonstrate deep levels of understanding about the world, and they are living and thriving today.

Dr Gregory Cajete, a First Nations Tewa academic from Santa Clara Pueblo, New Mexico, writes:

> Native [Indigenous] science is born of a lived and stored participation with the natural landscape. To gain a sense of Native science, one must participate with the natural world. To understand its foundations, one must become open to the roles of sensation, perception, imagination, emotion, symbols, and spirit as well as that of concept, logic, and rational empiricism.

Those who criticise the notion of Indigenous science will argue that culture is irrelevant to science, that the behaviour of atoms or the formation of

galaxies is not based on culture. But the rules that govern nature are distinct from the process by which we come to learn about them. That is a social activity. As a human endeavour, science is inseparable from culture.

Dr Lee highlights issues about the debate: ‘As much as there’s this idea that [Western] science is all rational and immune from culture, it’s simply not true. Science itself is not separate from culture. It came from a specific culture, and that is Western European.’

After studying the Western sciences used to produce knowledge about Torres Strait Islanders over the last century, Professor Nakata wrote: ‘By the time I fully read about the scientific method, the interpretations of data, and the conclusions drawn, it became clear just how culturally embedded the thinking and practices of Western science are.’

This emphasises an important question: what is culture? Dr Lee provides her perspective:

> Culture is the system of beliefs and worldviews that is mostly unconscious. Like the air we breathe, it surrounds us, is part of us, it is dynamic. It is the philosophical pillar of our identity as human beings going through this uniquely human experience.

For First Nations peoples, Indigenous concepts of science make no sense and have no meaning if they are separated from the people and their culture. Dr Lee explains that star knowledge is about so much more than science itself:

> Star knowledge brings a sense of purpose, a sense of hope, a lifeline that each person is connected to … to the bigger whole, the stars, the Universe. Those stars are more than just balls of gas. When we do Indigenous science, those stars are our oldest relatives. A sense of connectedness is a unique part of Indigenous science. In Western science, knowledge is often considered separate from the people who discover it, while Indigenous cultures see knowledge as intricately connected to people. It’s not like we’re just outside observers watching this. We’re a part of it.

I sat with an Elder on Mer (who chose to remain anonymous) and explained that part of what we are doing is showing the world that traditional systems of knowledge are also forms of science. Her response reflected a nearly universal view among the Elders: ‘Yes, of course we have science! We’ve been saying that for years, but no one will listen.’ For Māori physicist Dr Ocean Mercier the question of whether or not Indigenous people traditionally practise science is obvious: ‘Māori have always been scientists, and we continue to be scientists. Our science has allowed us to live, work and

thrive in the world for hundreds of years.'

Indigenous scholars conducting scientific research combine formal academic training and a personal lived experience that bridges Indigenous and Western ways of knowing. In the United States and Canada, this concept is called *Etuaptmumk*, meaning 'Two-Eyed Seeing'. Etuaptmumk comes from the Mi'kmaw language of eastern Canada and Maine, and was developed by Elders Dr Albert Marshall and Murdina Marshall. It involves seeing from one eye with the strengths of Indigenous ways of knowing, and from the other eye with the strengths of Western ways of knowing. Seeing with both eyes allows practitioners to find the middle ground that leads to mutual benefits for all. The Marshalls describe it as a 'gift of multiple perspectives'.

Another Mi'kmaw concept describes the importance of sustainability: *Netukulimk*. This focuses on protecting and managing the land through traditional laws and protocols that honour ancestors while protecting descendants. In Australia, Professor Nakata describes the importance of Indigenous star knowledge in developing sustainable practices to manage our collective future: 'The stars teach us how we should be looking after the planet. Why not look after it using the teachings of the Aboriginal and Torres Strait Islander people?

Different ways of knowing

Approaches in Indigenous science vary, as there are thousands of Indigenous cultures around the world thriving today, but you can see similar themes and characteristics between them. Western and Indigenous sciences work in different ways, with some crossover. Western astronomy uses mathematics as its foundational language. Indigenous Knowledges also include mathematical frameworks, which are embedded in language. Directionality is one example. In Western science we describe the world in relation to ourselves: my computer is in front of me, my cat is sleeping to my right and the door is to my left.

In the Warlpiri Aboriginal language of Central Australia, you do not describe positions of things with yourself as the focal reference point. Rather, your position is defined within the world around you. In Warlpiri, my computer is south of me, my cat is sleeping west of me and the door is east of me. It requires you to always know the cardinal directions (north, south, east

and west), no matter your orientation. Any one person is not the centre of the world, they are part of it.

In the 2017 film *We Don't Need a Map*, Aboriginal filmmaker Warwick Thornton examined the evolving meanings of the Southern Cross constellation and its impact on modern Australian society. One scene features two Warlpiri men constructing a traditional Southern Cross ceremonial ground. The men sit, laying out the framework using a plant fluff called *warmalu* to trace out the large, curved outline of the constellation. As they work, one of the men waves his hand and tells the other to 'move over', as the line is starting to look wonky. But he doesn't say 'move over'; he says, 'Go east, go east!'

Each of the cardinal directions signifies a meaning that is embedded in Warlpiri language and cosmology. Wanta Jampijinpa Patrick, a Warlpiri Elder, teaches that north corresponds to 'Law', south to 'ceremony', west to 'language' and east to 'skin'. 'Country' lies at the intersection of these directions, at the centre of the compass: Westerners conceptualise it as 'here'.

Indigenous sciences are highly interconnected, while Western science tends to be divided into different categories by discipline, with each diverging into ever smaller focus areas. Biologists, chemists, geologists and physicists can and do collaborate, but it is a challenge and does not happen as often as one would think. They tend to work within their own fields—each comprising what seems like an ever-increasing number of specialised sub-disciplines. Astronomers are usually divided between theorists and observers. Observers diverge between radio, optical and infrared. Radio astronomers further divide into high and low frequency, and so on. I have been told numerous stories by colleagues about researchers grappling with problems only to find out they had been solved long before by scholars in other disciplines.

Western science often searches for answers to very specific questions that may not immediately reveal broader applications. In many cases, the way it is commonly used today is incidental to its initial development. For example, in the 1970s, Australian engineer Dr John O'Sullivan was working in the Netherlands as a radio astronomer. He developed a mathematical algorithm to streamline the process of sorting radio signals from space. After moving back to Sydney and obtaining a job with Australia's government-run Commonwealth Scientific and Industrial Research Organisation (CSIRO), his team was instructed to find industrial applications of their research to

generate revenue. This algorithm paved the way for wi-fi.

Indigenous sciences are holistic, searching for meaning and links between systems. Application is the ultimate goal; if something is not useful, it is not generally considered important. Of course, ‘usefulness’ is a matter of perspective. While something may not have a practical application to agriculture, navigation or the development of seasonal calendars, it does not mean it has no practical use. Instead, it may inform ceremonies, spiritual practice or traditional Law.

Indigenous Knowledges provide solutions to sustainable living, adapting to changing environments and maximising the health of the land on a continental scale. When seeking out solutions, Professor Nakata advises us to be vigilant of certain tendencies that can occur:

> Strategies of conservation involve the collection, documentation, storage and dissemination of Indigenous Knowledge. When it employs methods and instruments of Western science, it becomes open to the same criticism of Western science. It becomes not embedded in local meanings and contexts but separated from its original context. It becomes an entity to be studied, worked on, developed, integrated, transferred and ultimately changed to fit another.

Dynamic knowledge

A foundational principle of science is that it must change and adapt with the introduction of new information. Yet throughout history, science has been stunted, suppressed and decried when new evidence supplants established views and ideas, especially those that are convenient for people in power. Galileo Galilei was put under house arrest in the 1630s by the Catholic Church for arguing against the accepted doctrine that the heavens are perfect; Charles Darwin’s theory of evolution, published in 1859, continues to be denounced by some fundamentalist religious leaders; and the science of climate change threatens the profits of the fossil-fuel industry and the politicians supported by its donations.

Indigenous science has long been rejected without consideration, overlooked, or exploited without recognition by powerful Western interests. Bio-piracy sees Indigenous Knowledge of plants stolen and patented for use in the food, cosmetic and pharmaceutical industries with little or no recognition or recompense. Indigenous star knowledge has been ignored, even when that knowledge clearly existed long before the ‘discoveries’ of Western science. This book provides several examples.

Just as Western science adapts and changes over time, so does Indigenous science. Archaeologists show that humans arrived to the land we now call Australia at least 65,000 years ago. Aboriginal cultures are often regarded as the oldest continuous cultures in the world, but that does not mean they have remained static. The environment has changed dramatically in that time. Ice ages came and went, sea levels rose and fell, forests morphed into deserts, mountains became islands, volcanoes and earthquakes altered the landscape, and the stars shifted in the sky. This requires the scientific understandings of the world to also change. Otherwise the knowledge becomes useless and untenable.

What is astronomy?

Astronomy is the science of the stars and one of the oldest subjects of enquiry. The stars serve as an anchor point of stability in a dangerous and ever-changing world. Their movements are largely predictable and dependable, holding true day after day.

Humans and animals alike have long utilised the stars for guidance. Nocturnal dung beetles orientate themselves by the glow of the Milky Way; turtle hatchlings instinctively know to scoot towards the shimmering reflection of moonlight on the surface of the sea; the Sun, Moon and stars help us to find direction, measure time and predict events on Earth. If we know how to read the stars we can know when the seasons change, when the tides rise and fall and when the weather will shift from calm to calamitous.

The stars also give meaning to our existence. The sky is a canvas of sparkling dots that we connect to form familiar patterns, to which we assign narratives about their formation and meaning. Across the sky, ancestors, heroic figures, animals, landscapes and fantastic beasts tell stories of the human experience. They speak of bravery and deceit, war and peace, sex and violence, punishment and reward. It is fascinating to find striking similarities in stories about the stars across vastly different cultures, with even more similarities in the ways they are utilised. You will read about examples of this throughout the book.

Like everything in life, the stars are not *permanently* fixed, nor are they *entirely* predictable. They slowly shift in their positions and reveal a fleeting and occasionally destructive side. New stars can appear suddenly and quickly fade away. Some fuzzy ‘stars’ resemble the long smoke of a campfire as they

slowly drift across the sky, night after night. Others zip across the heavens in the flash of an eye. On rare occasions, they can even fall to Earth with deadly results.

This unpredictability inspires awe and fear in the human psyche. Cosmic events can be perceived as warnings from displeased ancestors, the vengeance of angry deities or portents of disaster. The systems of knowledge about our world must include explanations for these transient events, even if they have little calendric application.

Indigenous Knowledge is passed down through story, song and dance. Systems of orality function differently to those of literacy. Oral traditions contain narratives that synthesise the scientific information, social practices and spiritual connections into a body of information that can be passed down orally while maintaining vitality. This includes the intangible and tangible: story, song, dance, craft, symbolic writing, ceremony and engineering. Some may dismiss them as ‘myth and legend’ but they are narratives that bring together systems of knowledge.

Readers interested in learning more about orality and memory are encouraged to read the books *Memory Craft* and *The Memory Code* by Dr Lynne Kelly, a science writer, educator and two-time Australian Senior Memory Champion.

What makes an astronomer?

If astronomy is one of the oldest sciences, then astronomers are surely among the oldest scientists. For as long as there has been what we might consider astronomy, there have been those who study, develop and teach it. And this astronomy was practised long before the invention of telescopes, cameras or supercomputers. In First Nations, astronomers are the keepers of knowledge that informs nearly every facet of life and culture.

In the western Torres Strait, an astronomer is called a *Zugubau Mabaig*, which literally translates as ‘star person’. David Bosun is a Moa (Mua) Islander and renowned artist, whose father was a Zugubau Mabaig. He describes this person as a

> keeper of star constellations, such as Tagai, Zugubau and Awai Tituil. The Zugubau Mabaig are taught in the kwod [place of higher learning] to read the star constellations. They use the stars as indicators and tell their Buai [kinship group] the right time for hunting expeditions at sea, and for planting and harvesting their gardens.

In the Pacific, Polynesian and Micronesian star knowledge is the realm of navigators. Their elite education requires them to learn the positions, movements and properties of hundreds of stars to guide long voyages across the ocean. They must know how to read changes in the properties and positions of the Sun, Moon and stars to predict wind currents, animal behaviour, cloud movement and weather. Navigators are taught in sacred schools and commit this detailed body of knowledge to memory—a topic we will discuss in Chapter 9: The Navigational Stars.

In Tonga, astronomers are called *Tiaborau* and are members of navigator families that hold chiefly ranks. They guard the knowledge of the stars and the secrets of their trade. Guardianship of star knowledge is also a family affair in Lakota cultures of the northern Midwest of the United States. Arvol Looking Horse, a Lakota Elder and spiritual leader, teaches that sacred star medicine is maintained by family lineages bearing the name Lúta. When he taught this to Dr Annette Lee, she revealed to him that her family's traditional name is Wanble Lúta, meaning 'Red Eagle'.

***Zugubau Mabaig* (astronomer), by David Bosun (2007)**

This hierarchical system ensures accuracy, rigour and competency of information. Given the importance of star knowledge to the survival of people and the thriving of culture, the role of an astronomer is generally considered one of the most prestigious and sacred roles in Indigenous societies.

In Australia, knowledge of the stars can fall into a variety of restricted realms, dictated by initiation or gender, or sometimes both. Restriction by gender is what some communities call Men's Business or Women's Business. The marks of initiation signify higher levels of understanding, respect and ability driven by a process of education and learning.

In 1898, Māori man Te Kōkau and his son, Rāwairi Te Kōkau, began recording traditional star knowledge in the Māori language. After 35 years, they had amassed a 400-page manuscript that contained over a thousand star names. Rāwairi passed the manuscript to his grandson, Timi Rāwairi. In 1995, Timi's own grandson asked him about Matariki, a celebration that kicks off the Māori new year, heralded by the dawn rising of the Pleiades star cluster. Timi went to a cupboard, pulled out the manuscript and handed it to his grandson, Rangi Mātāmua.

This sparked a 27-year journey that led to Matariki being recognised as an official public holiday in Aotearoa/New Zealand. Today, Professor Rangi Mātāmua is a globally acknowledged expert in Māori astronomy who won the 2019 Prime Minister's Science Communication Prize. He continues to study and translate the family manuscript, revealing deep layers of traditional astronomy that were thought lost to the sands of time. This jewel of knowledge survived over a century of ongoing colonisation and forms the basis of Professor Mātāmua's 2017 book, *Matariki: The star of the year*.

Similarly, Peter Eseli of Mabuiag Island (known locally as Mabuyag) in the western Torres Strait began writing down traditional knowledge in the Kala Lagau Ya language in the early twentieth century. By 1939, Eseli had amassed a 77-page manuscript, complete with drawings, songs and genealogies as well as a wealth of star knowledge, some of which is included in this book. He continued adding to it until his death in 1958. His manuscript was later translated into English.

The first astronomers?

Who were the world's first astronomers? The answer typically includes

scientists such as Galileo, Nicolaus Copernicus, or ancient civilisations that gave birth to what we consider Western science, such as Sumer in Mesopotamia. There is no question they were great astronomers and significantly contributed to what we know about the Universe today. As far as knowing who was first, we just don't know. It's all about context. The first astronomers of Australia are Aboriginal people. Their star knowledge goes back tens of thousands of years before the arrival of Western science in the eighteenth century. The same will apply to First Cultures around the world.

This book will show that the First Peoples of the world were the first astronomers. And therein lies the double meaning of Indigenous astronomy: it is the astronomy of First Peoples, and it is the astronomy that existed and thrived before the advent of Western science. It is *the* Indigenous astronomy. The point here is to show that astronomy was not developed solely in Western discourse and that Western science can learn a great deal from these ancient systems of knowledge that are passed down through cultural traditions.

UNESCO broadly defines Indigenous Knowledge as 'the understandings, skills and philosophies developed by [Indigenous] cultures and societies with long histories of interaction with their natural surroundings'. *Star knowledge* is the body of knowledge about the celestial realm and how it relates to a people, their land and their culture. *Indigenous astronomy* focuses on the empirical, scientific layers of this knowledge, and *Traditions* refer to the social practices, cultural activities, and methods of transmitting and applying this knowledge.

In *The First Astronomers*, we will look into scientific layers of Indigenous star knowledge that were developed long ago, demonstrate how this knowledge is embedded in day-to-day life, examine some of the discoveries attributed to Western scientists that were made by First Peoples, and explore how Indigenous and Western ways of knowing can work together for a mutually beneficial future. *The First Astronomers* is a glimpse into the extraordinary observational skills that are used in Indigenous practice and how astronomy serves as a guide to the human endeavour of understanding the motions of the cosmos and our place in the Universe.

CHAPTER 2

The Nearest Star

‘We are part of the environment: the Sun, stars, rain, trees … even the noise of a bird and the wind that rustles through the trees. We are a part of that. This is why the path of the Sun is very important for planting and gardening.’

—Uncle Alo Tapim, Meriam Elder

It was a stinking hot day in mid-December as I trotted across the small island of Mer. I was on my way to visit Uncle Segar Passi, a Dauareb man and the senior Elder on the island. He is considered an authority on traditional knowledge of the sky. He is also an internationally renowned, award-winning artist.

By the time I arrived, my face was glowing red in the midday Sun. Uncle Segar met me at the front of his house and invited me into his studio. Despite the lack of air conditioning, it was quite pleasant inside. The community built the studio especially for him to teach others about art. His artworks were mounted on the wall and scattered across the table. They were certainly gorgeous, but I knew they had much deeper significance. His practice focuses on natural scenes, and each colour, each brushstroke, each element has meaning and purpose. As for his colour palette, move over, van Gogh.

As we sat down, I mentioned the intensity of the Sun. He looked at me with a wry smile: ‘Yes, that’s why I stay inside during the middle of the day.’

We began a conversation about the stars, but I was curious to learn more about the Sun. After all, I felt its pounding influence as I wiped sunblock-infused sweat from my brow. I mentioned to him I’d noticed that in the tropics, the Sun seems to move high into the sky during the day and sets steeply at night. Dusk and dawn do not last very long; once the Sun goes down, it gets dark quickly. It is a stark contrast to life in Melbourne, where twilight seems to stretch out markedly.

Uncle Segar pointed out the window. ‘It is important to look at the Sun.

See where it sets … see what the clouds tell you. The Sun is in the south this time of year. We are going into the monsoon.' He pointed to his dusk paintings on the wall and showed me photographs of sunsets on his phone to illustrate his point. A love of sunsets is a passion we both share and our phones are full of photos of them. Uncle Segar takes photos of the dusk sky throughout the year to note changes in the Sun's position. I do the exact same thing from my apartment in Melbourne's inner west, where I have an unobstructed view of the western horizon—an ideal platform for stunning sunsets, as well turning my place into a fiery inferno on summer evenings.

The Elder explained that he keeps careful watch on the Sun and its position in the sky, day after day. He keeps track of it using markers in the background, such as houses, trees and light poles. He also uses his hands and fingers to measure the angle of the setting Sun along the horizon each night, to see how it changes. Uncle Segar explained what it meant.

The Sun sets in the south-west in December, but starts moving northward in January, February and March. Meriam people call this 'Lim eipuge eupamaretli'. It means longer days and shorter nights. In late March, the days and nights are of equal length. The Sun then starts to move along a different path in the sky through late June. It then becomes 'Lim dege eupamaretli': shorter days and longer nights. He mentioned that in just a few days, the Sun was going to reach its southernmost position on the horizon before turning and moving northward again. Our conversation took place on 17 December, just four days before the summer solstice.

Pointing to some of the artworks on his wall, Uncle Segar began describing the different types of clouds, what they look like, when they are visible and what they indicate. The clouds and weather, the land and sea, the animals and plants … they all link to the Sun, Moon and stars. Everything is related. Everything is connected.

Lakota Elder Arvol Looking Horse explains that 'Star knowledge is like a mirror. The stars are up there, and we have the stars down here.' This philosophical standpoint is understood in the Lakota/Dakota language with one word: *Kapemni*—'As is above, so is below: What is in the stars is on Earth; and what is on Earth is in the stars.'

You can understand connections between them if you know how to read the stars, the clouds and the land. The idea that 'everything on Earth is reflected in the sky' and of 'reading the stars' to understand your environment are two of the most common and widespread themes in

Indigenous astronomy. They are phrases repeated in some form by numerous Elders, and we will discuss them throughout the book.

Path of the Sun

The Sun is the giver of light, warmth, growth and life. It is at the centre of many First Peoples' knowledge systems, and central to our connection to the world. It can also cause death and destruction. As the most conspicuous and important object in the sky, understanding how the Sun moves is critical to survival. For Aboriginal Australians, its importance is recognised by its position at the centre of the national Aboriginal flag, developed in 1971 by Luritja artist Harold Thomas.

Knowledge about the Sun, and traditions describing how it came to be and why it moves the way it does, are as diverse and numerous as the cultures of the world. It is variably associated with a man or woman, creature or animal, deity or demon. The Moon is typically characterised as its partner, and the planets, and sometimes bright stars, are their children. What is central to these knowledges is the Sun's relationship to everything. The first place to start is to understand how it moves across the sky.

The path of the Sun is called the *ecliptic* in Western astronomy since it is along this path that eclipses occur. It represents the plane of the Earth's orbit around the Sun. The constellations through which it passes are recognisable to many: Scorpius, Taurus, Pisces, Leo, Virgo, Libra, Aries … the constellations of the zodiac. These are the constellations you will see in the direction of the Sun on the horizon after sunset or before sunrise.

First Peoples describe these movements in their own unique ways. Both Yolŋu and Tiwi traditions of northern Australia describe the Sun-woman carrying a torch across the sky each day, from east to west. When she reaches the western horizon, she moves beneath the Earth, travelling underground towards the east before rising again in the morning. As the Earth rotates from west to east, celestial objects appear to move from east to west, a term Western astronomers call *diurnal motion*.

The movements of the Sun serve as a timepiece that functions on different scales: daily, seasonally and annually. This impacts nearly every aspect of life. It guides the growth of plants and the behaviour of animals, marks the changing seasons and defines the length of a day.

In Aotearoa/New Zealand, Māori traditions refer to the Sun-man as Te Rā,

who used to travel across the sky too quickly for plants to grow or to provide warmth for the people. The ancestor-trickster Māui and his brothers captured Te Rā in a snare using rope and the jawbone of *Murirangawhenua*, one of Māui's kuia (grandmothers). They beat the Sun until he agreed to travel more slowly. You can see the ropes still attached to him as the Sun's light rays extend down to the Earth. A very similar tradition is taught by Winnebago Elders in the northern Midwest of the United States about a boy ensnaring the Sun where it rises.

The ecliptic is tilted towards the north in the southern hemisphere, and towards the south in the northern hemisphere. Many people in the southern hemisphere prefer housing with north-facing windows and balconies and that take advantage of the light and warmth of the Sun. Venture north of the equator, and that preference is for south-facing properties. First Peoples of the world follow the same preference, with homes, villages and cities constructed to take advantage of the Sun.

In the Central Desert of Australia, Aboriginal people explain the angle of the Sun in the sky in terms of the Sun-woman not liking the cold and choosing to roll away towards the north during winter. In Aotearoa/New Zealand, Te Rā travels back and forth between spending time with his summer-wife and his winter-wife, who are sisters. In the middle of the year, Te Rā travels north to join *Hinetakurua*, the Winter Maiden in the sea. She is represented by the star Sirius. In late June, Hinetakurua rises at dawn with her husband, signalling the arrival of winter. Te Rā then moves southward to join *Hineraumati*, the Summer Maiden on the land. She inhabits the Earth and is personified by the warm soil that encourages garden growth.

Meriam Elder Uncle Alo Tapim describes two pathways the Sun takes over the year. *Lim*, the Sun, takes a higher pathway in the sky during the wet *Koki* season, from December to March, and a lower pathway during the dry *Sager* season, from April to October. Knowledge about the changing angle of the ecliptic, and hence the Sun, is critical for gardening and agriculture. If one does not know where to plant crops appropriately, the result will be a failed harvest.

Uncle Alo explains:

> The path of the Sun is very important to management of land and how land can be very productive. I cannot plant my yam where the Sun will not get to it. I have to put it where the sunlight will reach it. When a Meriam [person] sees a banana has been planted where the Sun cannot get to it, the gardener responsible is branded as a person who is ignorant about what the Sun provides.

> It is also about timing. The person who ‘does not know’ will plant in the lugidim [shade of a tree or shrub]. If a yam is planted there, no Sun will reach it … no warmth, no nothing, like in the middle of the rainforest. The plant will come up, but it will be very weak.
>
> A Meriam is not a nomad. We have an area we look after, and we know how each element plays a part in that. A Meriam is part of that environment: the Sun, stars, rain, trees … even the noise of a bird and the wind that rustles through the trees. A Meriam is part of that.

Solstices and equinoxes

Understanding the cycles of nature means making careful observations of the ways celestial bodies move over time, and how long these movements take to repeat. Some Elders describe nature as a series of overlapping cycles. Just as the plants and animals have their own cycles, so do the seasons, the climate and even the landscape. They all occur over different timescales.

The Sun moves through its own unique range of cycles. It rises and sets each day. It moves back and forth along the horizon as it rises and sets over the year. Sunspots cycle in eleven-year increments. Since everything is connected, these cycles overlap with the cycles of the Moon, planets, stars and everything on the land. Understanding this requires an observer to know the reference points from which these movements can be measured to calculate their durations.

In some cultures, the Sun is characterised as two different entities, such as a parent and child, or sisters. Guugu Yimidhirr Elders in northern Queensland describe the Moon as a man married to a pair of sisters. Each sister represents the Sun at different times of the year, who take a different path across the sky, similar to the Māori traditions of Te Rā. The older sister visits him in the cold season, while the younger sister visits him in the hot season. These underlying observations are due to the Earth being tilted on its axis by 23.5 degrees. As the Earth orbits the Sun, the angle of the ecliptic as seen by an observer will change over the course of a year, being higher and more directly pointed at the Sun during summer months and angled away during winter months. Solar-based seasons in the northern and southern hemispheres are exactly the opposite.

Observation of the Sun’s pathway is central to First Peoples’ application of knowledge to agriculture, architecture, engineering and calendar development. The changing angle of this pathway affects where the Sun rises and sets on the horizon throughout the year. Elders like Uncle Segar keep track of this. It changes each day, moving back and forth between the two extremes that Western astronomers call the *solstices*, a name derived from the

Latin words *sol* (Sun) and *sistere* (to stand still). The Moon and planets have their own equivalent, which are called ‘standstills’ for the same reason.

We see that the point on the horizon where the Sun rises and sets each day gradually moves northward, stops, then turns southward until reaching a southerly extreme. It then turns northward again, cycling back and forth over a year. This back-and-forth motion is described as ‘rolling’ by Aboriginal people in the Central Desert, who say the Sun-woman ‘rolls away’ towards the north during ‘winter’ (since the Sun appears as a disc), as well as in the Māori traditions about Te Rā.

In the southern hemisphere, the most northerly point on the horizon where the Sun will rise or set marks the winter solstice, commonly called ‘midwinter’. This occurs on or around 21 June. When it reaches its southernmost extreme, it is the summer solstice. This is when we experience the longest period of daylight and shortest night, just as described by Uncle Segar. This occurs around 21 December. Like the seasons, the solstices are exactly opposite in the northern hemisphere.

The midpoint between the solstices is when the Sun rises due east and sets due west. This marks the *equinox*, a term derived from the Latin words *aequus* (equal) and *nox* (night). On these days, we get equal amounts of day and night. The equinoxes are split between *vernal*, from the Latin term *vernalis*, meaning spring, and *autumnal*, from *autumnalis*, meaning autumn (fall). These solar points define the four European-based seasons: winter, spring, summer and autumn. Each season lasts approximately 91 days, or about three months.

The solstices and equinoxes are well-known phenomena in the knowledge systems of First Peoples, even if their seasons are not defined by these points. Meriam Elders in the Torres Strait describe how the length of day is related to the position of the Sun at these extremes. In Māori traditions, they are termed *Te takanga o Te Rā*, which literally translates to ‘the turning place of the Sun’. The Sun’s sharp back-and-forth movement over the course of a year is represented in zigzag motifs that the Bambara people of Mali in western Africa use to decorate their granaries. The contents of these granaries are the product of observing the shifting position of the Sun throughout the year to harvest crops.

Marking the solstices is one of the oldest and most widespread cultural practices associated with the Sun. It is critical for marking time and changing seasons with a wealth of interrelated applications. Noting the position of the

Sun at the solstices, or equinoxes, requires an observational point of reference. Different cultures have solved this problem by using a range of techniques that fall into three general categories: using natural objects, such as a mountain peak or valley, as viewed from a specific location to mark the Sun's position; using wooden beams or large stones that have been moved into place for this purpose; or a combination of the two.

An indirect method of marking the solstices involves measuring shadows. The shadow of a tree or stick in the ground will mark out the changing position of the Sun throughout the day. Markers can be placed at the tip of the stick's shadow at different times. The line connecting them is exactly due east–west. The length of the shadows, however, will depend on the angle of the Sun in the sky from solstice to solstice. The length of the shadows is greatest at the winter solstice. Kamba people of Kenya in east Africa draw lines in the ground that trace the shadows of trees at a given time throughout the year. These lines point to the northern and southern extremes of the Sun's position at the solstices.

It is important to remember that the range of the solar points along the horizon, from summer to winter solstice, is not uniform across the globe. Because the Earth is a sphere, the spread of these points varies by an observer's latitude. In Darwin at the top end of Australia, the spread between winter and summer solstice is about 48 degrees across the horizon. In Hobart, at the southern end of the country, that spread is 66 degrees. This means that creating tools to mark the solstice points is not the same everywhere. These tools, as with most Indigenous Knowledges, are developed locally.

The most famous examples of tools used to mark out the solstices focus on stone circles and burial mounds. England's Stonehenge is the most well known, dating back over 5000 years. It is orientated in such a way as to clearly mark the position of the rising Sun at the solstices. Observers in the stone arrangement's centre will see the midsummer Sun rise behind what is known as the Heel Stone to the north-east. The midwinter Sun will rise in the south-east when observed from the enclosure's entrance. Stonehenge may be the most famous, but it is not the only or earliest example. Newgrange (*Sí an Bhrú*) is a large monumental burial mound in Ireland dating back 5200 years, two millennia before the Celtic era. Light from the rising Sun at winter solstice passes down a 19-metre passageway, dramatically illuminating a chamber for a few minutes out of the entire year.

In the Andes mountain range of Peru lies a large ancient complex called

Chankillo. The site includes a large ridge running north–south, on which thirteen towers were constructed. The towers are equally spaced and when observed from special ceremonial points to the east and west of the ridge, one can see the Sun rise or set exactly over each tower throughout the year. Chankillo is thought to have been constructed around 2300 years ago, making it the oldest solstice-marking monument known in the Americas to date. Among the oldest known sites in the world that contains confirmed alignments to the solar points is Nabta Playa in the Nubian Desert of southern Egypt. The site contains a circle of stones aligned to the summer solstice and is approximately 6800 years old.

Aboriginal and Torres Strait Islander peoples also observe the solstices and use this knowledge in interrelated ways. Colonists did not acknowledge this, however, and when non-Indigenous people learned about solstice observations and practices from Elders, they seemed rather surprised. In 1932, writer Mary Gilmore, then living on the north coast of New South Wales, wrote about her father's astonishment and 'sense of discovery' at finding out that Aboriginal people knew the solstices 'just as truly as we [Westerners] did'.

> I was too young to keep in mind all that he said about how they measured for the period, except that it was done by means of certain fixed mountain-rocks known to the tribes. One of these was somewhere near the head of the Clarence River. It was a rock mass that neither earthquake nor landslide could shake out of position. When the Sun's edge at setting just touched the down line on one side of this rock, it marked the period of the Sun's turning … the solstice was either just then, or within so many days of that. Watch was kept by those chosen for this duty, which was the utmost importance, the year being measured by it, and tribal ceremonies dependent on it for date.

This description is one of many that illustrates how Aboriginal people use natural objects to mark the solstice points. Just as Gilmore noted that 'Watch was kept by those chosen for this duty', Elders describe people in the community whose job it is to sit on high ground, such as hilltops, to carefully watch the changing positions of the Sun, Moon and stars. As we learned in Chapter 1: Star Knowledge, this person is called a Zugubau Mabaig in the western Torres Strait. One of the Zugubau Mabaig's duties is to watch the position of the setting Sun throughout the year to mark out important times, seasonal change, and the behaviours of plants and animals.

Sharing knowledge from his father, Uncle David Bosun teaches a localised way of observing the setting Sun's position across the year. He led me down

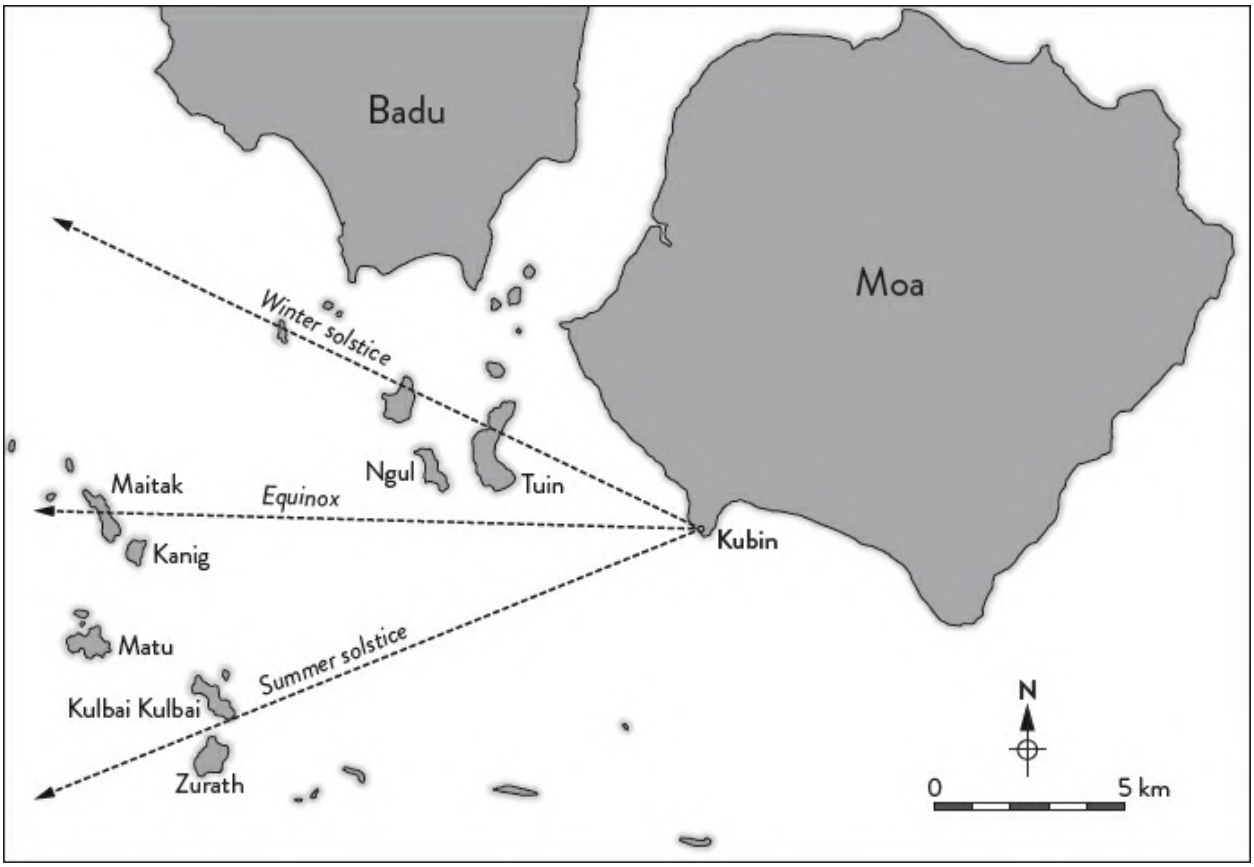
to the dock in the village of Kubin, on the southwestern coast of Mua. He pointed out how the people observe the position of the Sun setting behind an archipelago of islands to the west. The Sun setting over and between these islands during its northerly then southerly migration signals events happening in the local environment.

During the winter solstice in late June, the Sun sets at its northernmost point, over a small hill on the island of Tuin. The setting Sun gradually moves southward each evening. When it sets between the islands of Tuin and Matu, the people know that the cooler south-easterly winds of the dry Sager season will begin shifting to the still doldrum, lasting from September to October. When the Sun sets over the north edge of a large hill on the island of Maitak, that is the midpoint of the solar range when the days and nights are of equal length: the equinox.

The position of the setting Sun continues to move southward each day as it passes the vernal equinox. In mid-October it sets over Matu, signalling the start of *Soewlal*—turtle-mating season. This lasts through to late November as the Sun sets over the sea between the islands of Matu and Kulbai Kulbai. When the Sun reaches the latter island, it signals the end of the dry season and the start of the monsoon. This is when mating turtles float on the surface of the water and are easy to catch or spear.

The Sun reaches the summer solstice when it sets along the southern tip of Kulbai Kulbai, coinciding with the start of the wet *Kuki* season (the monsoon is called Kuki in Kala Lagau Ya and Koki in Meriam Mir). At this spot, it appears to meet with the island of Zurath. The position of the rising and setting Sun then begins shifting northward each day. A few months later, the wet north-westerly winds start transitioning to the dry south-easterlies as the autumnal equinox passes in March, where it sets just north of Matu.

By mid-April, the Sun sets along the southern edge of the islands Tuin and Ngul. April is a critically important time of year. The rains of the wet season have boosted growth of root vegetables, so this is the month to harvest. This period is called *Kek*, referring to the star Arcturus. Kek means ‘yam star’, and its rising at dawn in late April signals the end of the monsoon and the time to harvest yams. It is marked out by an important ceremony. The setting Sun gradually slows in its nightly northerly migration until it stops when reaching the winter solstice in late June.



Positions of the Sun setting over islands to the west of Moa in the Torres Strait

Sunspots

Natural cycles linked with the Sun go beyond the annual cycles of the solstices. Elders teach how longer-term cycles relate to sunspots, an area of Indigenous Knowledge that is poorly recognised outside of those communities. Just as the Moon has dark spots on its surface (called maria, which we will learn about in the next chapter), the Sun, too, has its own dark spots. But unlike the Moon's maria, sunspots change in number, size and appearance over time. Sometimes none are visible at all.

Sunspots can be a challenge to see, given the intensity of the Sun's brightness. Looking for them is a dangerous task, as staring at the Sun can cause serious damage to our eyes. Under the right conditions we can see them with reduced (but not insignificant) risk, such as at sunrise or sunset, or if clouds, fog, haze, dust or smoke dim the Sun's light enough to see. Sunspots also need to be of sufficient size for us to be able to resolve them with our

eyes under these conditions. The Sun is 150 million kilometres away. Considering the limits of human vision, a sunspot needs to be 50,000 kilometres in diameter for us to see it, which is four times the size of the Earth! This may seem enormous, but ‘enormous’ is relative; it represents only 3.6 per cent of the Sun’s diameter.

Ancient astronomers in China, Japan and Korea kept written records of sunspots, as did cultures in India, Greece, and possibly Egypt and Arabia. Hervé Paniaq, an Inuit Elder from Iglulik in Arctic Canada, teaches a tradition about how the Sun-woman, Siqiniq, formed spots on her body as an act of self-harm, while her brother, Taqqiq the Moon-man, formed the maria on his face by falling on a candle. First Peoples in Brazil have a remarkably similar tradition about the formation of sunspots and lunar maria as the Inuit of Iglulik.

First Peoples clearly saw sunspots and recorded them in their oral histories. But how was this accomplished? The Aztec civilisation of Mesoamerica, in what is now Mexico, appeared around the early thirteenth century and lasted until Spanish conquest and colonisation in the sixteenth century. Aztec traditions describe the formation of the Sun, which included a procession of people who were chosen by a council of gods to take the role of ‘Sun-god’. Four people had already taken this role, but the higher gods were not pleased with them. They chose two men, Tecciztecatl and Nanahuatzin, for this position. The men were given the task of sacrificing themselves by jumping into a large bonfire.

Tecciztecatl was driven by a selfish desire to be immortal but was a coward. He tried several times to jump but could not gather the courage. Nanahuatzin was humble and saw this role as one of duty and obligation. He jumped into the fire without hesitation. Embarrassed and with his ego crushed, Tecciztecatl jumped in immediately after. Both men ascended into the sky as two Suns.

One of the higher gods was enraged at Tecciztecatl’s cowardice. He grabbed a rabbit and threw it in Tecciztecatl’s face. This dimmed his light, and he became the Moon. The remaining Sun, Nanahuatzin, remained stationary in the sky, scorching the Earth with his heat. Nanahuatzin’s name means ‘full of sores’ as he is deformed by syphilis, leaving pockmarks across his face. The description explains the rabbit-shaped maria on the Moon and indicates the presence of dark spots on the Sun.

In *The Florentine Codex*, a sixteenth-century ethnographic study,

Franciscan friar Bernardino de Sahagún wrote that Aztec warrior spirits protected their eyes from the brightness of the Sun-god by covering their faces with their shields, but they could still see it through the small holes made by arrows. The warrior who could see the Sun best was considered the bravest. It shows a probable method used by Aztecs to observe sunspots. By poking a tiny hole into something that blocks out most of the Sun's glare, the hole can project a tiny beam of light onto a surface. When held at the right distance from the pinhole, you will see an image of the Sun form, where you will be able to see sunspots. It's not safe, but it works.

The Aztec calendar was based, in part, on the earlier Mayan calendar. Evidence in Mayan traditions indicates they, too, observed sunspots. Pictograms of the Mayan Sun-deity show him with and without spots on his cheeks. Many of the pictograms can be dated with a high degree of accuracy. Studies have shown that spots appearing on the cheeks of the Sun-god in these pictograms occur in years of high sunspot activity. At times of low or no sunspot activity, they are not commonly featured on the deity's face.

Solar cycle

In Zambezi traditions of Mozambique in southern Africa, the Moon is a woman who was deeply jealous of the Sun-man, who was adorned with glittering feathers of light. One day, when the Sun was looking away to the other side of the world, the Moon-woman took advantage of this and stole some of his feathers to decorate herself. When the Sun-man discovered her transgression, he threw mud at her. This stuck to her face as the Moon's maria and has remained there ever since. Seeking eternal vengeance, the Moon-woman perpetually waits until the Sun-man is distracted. Utilising the element of surprise, she throws mud back at his face. The people say when this happens the Sun has large spots and has some difficulty shining. But the Sun does not retaliate, as this only happens every ten years or so.

The antiquity of this knowledge is unknown, but Zambezi traditions describe something that Western science recognised only in the eighteenth century: that sunspots are cyclic. Danish astronomer Christian Horrebow recorded observations of sunspots between 1761 and 1775. He realised that the number of visible sunspots seemed to wax and wane over a period of several years. In 1843, German astronomer Samuel Heinrich Schwabe looked through his own sunspot data, which spanned seventeen years. He, too, found

a cycle of repeating sunspot numbers. Today, Western science recognises a solar cycle that ranges from ten to twelve years, with an average of just over eleven years. This is something that the Zambezi people, as well as cultures in the Congo, figured out long ago through careful observations and curating long-term oral records.

In Western science, the appearance of sunspot numbers is related to the Sun's physical structure. Sunspots are areas on the Sun where it is more magnetically active, with this activity taking the form of solar flares and coronal loops that eject large amounts of energy and highly charged particles into space. When these blasts reach the Earth, they are accelerated towards the poles by our planet's magnetic field where they energise molecules of oxygen and nitrogen in our atmosphere. The collision causes those molecules to release energy as light, which can appear in different colours, shapes and intensities. This is a phenomenon that is well known to First Peoples, particularly those at latitudes closer to the poles. This is the light of the aurora.

Auroras

In April 2021, I was privileged to join Gomeroi astrophysics graduate Krystal De Napoli and Brisbane Planetarium director Mark Rigby as the Lead Astronomer on Melbourne's first-ever Aurora Flight. This saw 240 astronomy enthusiasts and space fanatics board a Boeing 787 bound for the far southern seas towards Antarctica to see the southern lights. As the cabin lights dimmed and our eyes adjusted to the relative darkness, a faint white arc of light appeared across the sky. As our eyes continued to adjust, we could see an unmistakable green glow, stretched as waves and arcs across the backdrop of stars: the dancing green curtains of the *aurora australis*. I had never seen an aurora before and the experience was breathtaking.

These strange, multicoloured, glowing and sometimes moving lights have been featured in the knowledge systems of First Peoples across the world, primarily those at high latitudes near the Arctic, or southern latitudes of Aotearoa/New Zealand and Australia. Māori traditions refer to the southern lights as *Tahunui-a-rangi*, meaning 'great glowing sky'. In 1869, a Māori man from Wanganui explained to ethnographer Elsdon Best that his ancestors migrated to Aotearoa on a series of *waka* (canoes). One waka continued sailing south towards the horizon. Māori traditions say the crew settled a land

far to the south and the auroras are their campfires.

The term *aurora* comes from the Greek word for ‘sunrise’, and later the Roman goddess of dawn. It is known as the *aurora borealis* in the northern hemisphere and aurora australis in the southern hemisphere. The northern term was coined in 1619 by Galileo from the Latin term *boreas*, meaning ‘north wind’. The lights of the aurora are technically visible from anywhere on Earth but are more commonly visible from higher and lower latitudes closer to the North and South Poles.

In Australia, Elders variously describe these lights in relation to ashes, blood, fire and evil spirits. Traditions based on these lights are commonplace in the southern half of the continent, but Aboriginal cultures as far north as Queensland and the Northern Territory also feature them in their traditions. Since these lights are not reliable indicators for annual calendars, they generally serve as a reminder of traditional Law and social expectation.

Pitjantjatjara traditions from Uluru in Central Australia teach of hunters killing and cooking a *kalaya* (sacred emu). As it was a breach of Law, the hunters were cast into the sky. The red smoke of their celestial fire is occasionally seen to the south, towards the land of Tjura (referring to a place of red glowing light). The white and red glow of the aurora australis represents the poisonous flames of this fire, serving as a warning not to break this taboo. Every appearance of the southern lights strengthens that connection to Law.

Along the coast of Victoria, Aboriginal traditions describe natural disasters that coincide with the appearances of the southern lights. In Gunai Country of south-eastern Victoria, the lights are described as a physical manifestation of a powerful sky-ancestor’s anger. Elders teach that the ancestor, Mungan Ngour, set the rules for initiating boys into manhood. He put his son, Tundun, in charge of these ceremonies. Knowledge about initiation is restricted to men, making it taboo for women to learn about it. Someone broke this Law, infuriating Mungan. He cast down a fire to the Earth, which the people saw as a powerful light display that filled the sky. The people turned on each other, and were killing one another when a tsunami rushed in, causing untold destruction. Today, people are permitted to continue initiation ceremonies, but if secret knowledge is shared, Mungan will again fill the sky with these lights.

Auroral cycles

The Zambezi traditions that describe the cyclic appearance of sunspots every decade indicate longer-term observations of the solar cycle. This, in turn, is related to the frequency and intensity of auroral displays. However, auroras are extremely rare in southern Africa, so it is not surprising that those traditions do not mention the lights in relation to sunspots. First Peoples at latitudes where auroral lights are more common did make this connection long ago.

In Australia, Aboriginal traditions relate the cyclic appearance of auroras to longer-term calendars. Aunty Frances (Fran) Bodkin, an Elder from Sydney, teaches that Dharawal people traditionally use the appearance of the *tangara* (aurora) to announce the start of the eleven-year *Mudong* weather cycle. Auroras tend to appear during the annual *Ngoonungi* season. This is a period of gradual warmth that occurs during the months of September and October. The appearance of the aurora signals the beginning of *Gadalung Burara*, the first of the eight Mudong cycle phases. This hot and dry phase can last for up to twenty complete lunar cycles, but no more. Aunty Fran cites October as a time when auroras, which appear to the south and west, are more clearly visible. An examination of records that mention Aboriginal observations of auroras shows that they all coincided with years that experienced peaks in sunspot activity. They also occur primarily around February–March and September–October.

In 2003, Aunty Fran explained that the eleven-year Mudong cycle started in 2001 with the appearance of the aurora australis. This coincided with a maximum in the solar cycle that dropped to its lowest point by the start of 2009. Her description of the Gadalung Burara as a hot dry phase is something related to an area of intense study. There has long been a suspected relationship between sunspot cycles and droughts, and several scientific research papers have been published arguing this hypothesis. This is an example of Indigenous Knowledge that can inform and guide Western science.

Aunty Fran’s teachings explain this trend and support modern geophysical research showing that geomagnetic storms tend to peak in the months around the equinoxes, when the Earth’s northern and southern hemispheres are most evenly exposed to the solar wind and the interplanetary magnetic field. The magnetic fields between the planets and the Earth oppose and essentially cancel each other out. When this happens, holes form in the Earth’s magnetosphere. This enables particles from solar wind to enter our

atmosphere more easily, resulting in brighter and more frequent auroras. Space scientists call this the Russell–McPherron Effect, named after two geoscientists who described this in the early 1970s.

Auroral sounds

The traditions of First Peoples ranging from Australia to Greenland tell of strange sounds associated with the auroras. They are reported as whistling, crackling and hissing, and sometimes as emulating the sound of rustling grass or a person walking through snow. In the twentieth century, people thought it sounded like radio static. The Sámi people of northern Europe refer to auroras as *guovssahas*, meaning ‘the light you can hear’.

Inuit traditions from Iglulik associate the sound of an aurora with the noise made by spirit ancestors playing a ball game in the sky. It also signifies attempts by the sky ancestors to communicate with the people on the land. In some Inuit traditions, if one hears an aurora and whistles back, the light of the aurora will come nearer as it makes the ancestors curious.

In 2021, Dené man Ryan Dickie from Canada’s Fort Nelson First Nation ventured north to photograph the auroras. He was taken aback when he saw the auroras and heard a sound:

> When you’re living up here you hear stories that the northern lights make a sound, and if you whistle at them that they’ll come closer to the ground. My grandma told me a story when they were kids growing up on the land near the Liard River about how the northern lights made clicking sounds, like you’d make to call your dog.

Mamie Williams, a Tlingit woman from Hoonah, Alaska, said her grandmothers taught her to listen for the northern lights when she was a child. ‘It’s our ancestors letting us know, “We crossed over but we’re still here with you.”’

She explained that she first heard an aurora when she was fourteen years old and has since heard what sounds like drumming when the lights are dancing above. ‘The brighter they get, the more you hear.’

This is a clear indicator that the intensity of the auroras is proportional to the volume of the strange sounds they make. In Tasmania, Aboriginal people near Hobart said a brilliant, multicoloured aurora made a crackling sound like ‘people snapping their fingers’. From the opposite ends of the globe, we find clear accounts associating brilliant auroral displays with peculiar sounds.

Despite the large body of traditional knowledges linking aurora to sound, the scientific community dismissed it as ‘folklore’. But other scientists began to experience these sounds themselves, and they could no longer ignore or dismiss it. It was time for Western science to take it seriously, even if long overdue. Guided by Sámi and Inuit traditions, a team of Finnish scientists set out to find evidence that auroras and sound are connected.

The team, led by Professor Unto Laine, travelled to the north of Finland and set up a complex multi-microphone system with a very low frequency (VLF) loop-antenna. What they recorded during an auroral display confirmed what Sámi, Inuit and Aboriginal people had long been saying: auroras and sound are related. In 2016, the team presented their findings at the Baltic-Nordic Acoustic Meeting in Stockholm, Sweden. Based on their experiment, they developed a scientific explanation for the link.

On occasion, a layer of air forms in the atmosphere that increases in temperature the higher you go, rather than decreasing. When this happens, the cooler, denser air nearer to the ground builds up electrical charges from incoming space particles. When charged particles from the Sun hit our atmosphere, they form the lights of the aurora. They also ‘overload’ the electrical particles in the lower atmosphere, causing them to discharge. When this happens, we hear it as sound.

CHAPTER 3

The Moon

‘The eclipse celebration and ceremonies are planned in advance and are advised by the Zugubau Mabaig. As an astronomer he knows when the eclipse will take place.’

—David Bosun, Mua artist

One warm, hazy night I decided to head out for my evening walk through Lane Cove National Park in the northern suburbs of Sydney. As I passed through the gates and strolled down the road, I noticed the asphalt was eerily illuminated by the light of the Full Moon. This is my favourite time to go for a walk, and the music of Seattle band Sky Cries Mary in my earbuds gave it a psychedelic feel. When I passed a small clearing, I looked up and saw the Moon emerge from behind the trees. It was hazy and circled by a bright, distinct ring, which resembled a thin rainbow engulfing the Moon. Entranced, I remembered something I had been taught by both Aboriginal and Torres Strait Islander Elders: a ring around the Moon is a sign bad weather is coming.

If you want to know when this will happen, count the number of stars between the ring and the Moon. Elders say that the number of stars you can count will signify the number of days until it rains. If you cannot count any stars, rain is imminent. I searched but could not see any. The Moon was giving off a bluish tinge. The evening was beautiful, so I carried on with my walk.

The next morning, I awoke to a thunderclap. It was pouring.

The ring around the Moon is called a halo, and its appearance signals approaching rain to cultures around the globe. I had never thought much about the Moon being useful to forecast weather or predict seasonal change, but this turned out to be commonplace. The Moon is the largest and brightest object in the night sky and the systems of knowledge about it are as complex and rich as anything I have studied. An entire system of science is centred on

the Moon, forged by deep knowledge about its movement, phases, changes in appearance, connections to the land and sea, its links to the behaviour of plants, animals and even people.

Maria and earthshine

Arguably one of the most distinguishing characteristics of the Moon is the dark patches covering its surface. As with clouds in the sky, everyone can make out various shapes and interpret these dark spaces differently. On the eastern coast of Tasmania, Aboriginal traditions describe how the Sun-man, Parnuen, fell in love with a woman he saw preparing fish on an iceberg. When he came down to meet her, she slipped and fell into the fire, causing burn marks on her face, which were smudged by ash. She then joined him in the sky as the Moon-woman.

In north-western Victoria, the Boorong name for the Moon is *Mityan*. Mityan is a quoll, a spotted marsupial that resembles a cat. He was attacked by the jacky lizard, Nganurganity (also spelt Unurgunite), for trying to steal one of his two wives. The beaten-up Mityan now wanders the heavens as the Moon, the bruises on his face signified by its dark patches. This, like many traditions from Australia to Europe, Asia to Africa, features someone who was cast into the sky as the Moon as punishment for breaking Law, serving as a constant reminder about the importance of acceptable behaviour.

In the Torres Strait, maria form the silhouette of a woman weaving mats out of dried coconut leaves. Her name is *Aukam*, and she loved to weave at night by the light of the Moon. When the Moon-man noticed that Aukam worked only in the light of his glow, he figured she was in love with him. He came down and took her with him up into the sky where she can be seen today.

There are many descriptions of the dark and bright patches on the Moon, which are commonly associated with ash or bruises. If we look closely when it appears as a thin crescent, we can see that the otherwise ‘dark’ part of the Moon’s disc emits a faint glow. A traditional story from the Tiwi Islands of the Northern Territory in Australia explains this phenomenon, as well as the origin of the Sun and Moon.

In the old days, the Tiwi people were immortal. A man named Purukupali had a wife and an infant son. One day, while he was away, his wife had an affair with a man named Tjapara. While she was distracted, a terrible tragedy

befell her son. Filled with rage, Purukupali attacked Tjapara and beat him with spears and clubs. Tjapara escaped into the sky and became the Moon. The maria of the Moon are the scars on Tjapara's face from Purukupali's attack. Each month he wanders the heavens, eating mangrove crabs until he fattens into a Full Moon. This makes him ill and he wanes away and dies for three days. He re-emerges from death as the New Moon, appearing as a thin crescent, which signifies his skeletal ribs. The faint glow visible on the remainder of the Moon signifies his spirit, *Imunka*. Western astronomers call it *earthshine* and describe it as sunlight reflected by the Earth's atmosphere onto the Moon's surface. Since that event, Purukupali decreed that no living being would come back to life after dying. Only Tjapara partially escaped this fate, with his changing phases reminding the people about the cycle of life and death.

Phases

A Nuennone oral tradition from Bruny Island off the south-eastern coast of Tasmania describes the dynamic between the Sun-man (Punywen) and the Moon-woman (Venna). In the beginning, they travelled together across the sky. But Punywen moved too quickly for Venna, and she began to fall behind and started resting on icebergs. As Punywen moved further away from the Moon-woman each day, he illuminated more of her each night to encourage her to catch up with him. This description demonstrates that the people recognised the Moon's light as reflected sunlight.

Western science takes a somewhat limited approach to naming lunar phases. They are divided between four points and four transitionary phases that depend on how much of the Moon is illuminated. If less than half of the Moon is illuminated, it appears as a *crescent* shape. If more than half is lit, it is called *gibbous* (a term originally meaning 'hump-backed'). The period where more of the Moon is being illuminated each day is called *waxing*, whereas when less is illuminated each day, it's called *waning*. The Moon is always half-lit by the Sun. The angle of the Moon relative to the Earth affects how much we see of the lit side.

When the Moon is near the Sun, we are looking at the back of it. Western astronomers call this the New Moon. Then it waxes as a crescent shape until half is illuminated at the First Quarter. The Moon continues waxing as gibbous (more than half illuminated) until it fills as a Full Moon, then it

begins waning away as a gibbous Moon until the other half is illuminated (Last or Third Quarter). When it has completely waned as a crescent it ‘dies’ for three days back to New Moon.

The Moon appearing to waste away and die is a common motif in the traditions of cultures around the world. Many different Aboriginal traditions teach that all humans were once immortal, but the Moon was a man who did something wrong and now wanders the heavens. He waxes and wanes each month, getting fatter then wasting away until he dies for three days before returning to life. His actions caused mortality for all people and serve as an eternal reminder about the importance of appropriate behaviour. In South Australia, Jarildekald Elders teach that the waxing Moon represents the Moon-woman, who is pregnant and coming to term. Indigenous traditions commonly link the Moon phases with love and fertility.

The lunar phases represent a cycle of life and death, punishment and reward, selfishness and generosity. This cycle has a period of 29.54 days. This is called ‘a Moon’ or *lunation*. This is why so many Indigenous words for the Moon also relate to a lunar month. In Meriam Mir, both are called *meb*. In Kulin languages of south-central Victoria, the term *carnboo meniyan* refers to a lunar month, translating as ‘one Moon’ or ‘one lunation’. The duration of a lunar month is different to that of commonly used Julian or Gregorian calendar months, which average 30.44 days.

Lunar months are linked to various practices, such as gardening, fishing, navigation and celebration. Polynesian cultures of the Pacific developed Moon calendars long ago. In Hawaii, they are called *Helu Pō*. Johanna Kapōmaikaʻi Stone and Rachel Kapule teach 30 unique names for the Moon’s period of lunation: one for each day of the lunar cycle. The 30 names are divided into three *anahulu* (ten-day sections) that form the total *malama* (month).

The first anahulu is the *hoʻonui*. It signifies the waxing period of the Moon, from when the crescent is first visible until a few days after the First Quarter, when it starts to round out. The second anahulu is the *poepoe*, a time when the Moon is nearly full. It lasts for ten days until the Moon wanes to just before the Last Quarter. The third anahulu, *hoʻēmi*, starts at Last Quarter Moon and lasts until it wanes away to invisibility, finishing on the day before the first visible crescent of the Moon appears.ʻ

Tides

We experience two high tides and two low tides every day, spaced six hours apart. Aboriginal people of Oyster Bay, on the east coast of Tasmania, call the high tide *Neanta Payawaree* (Woman Tide) and the low tide *Loo Payawaree* (Child Tide). The pulsation of the tides correlates to the phases of the Moon. First Peoples worked out long ago that high tides always occur when the Moon is directly overhead *and* directly below us. Low tides, as several Elders pointed out, always occur when the Moon is near the horizon.

The gravity of the Moon pulls against the Earth, drawing the malleable oceans towards it. This causes them to bulge towards the Moon, forming high tides. Due to the conservation laws of physics, a bulge forms on the opposite side of the Earth as well. As the Earth rotates, our angle to the Moon changes, and so do the tides. When the Moon is near the horizon, then we are in between the sides of our planet where high tides occur. This is when we experience low tides. The gravity of the Sun also tugs gently on the seas. When the Moon and the Sun are in alignment, their combined gravity pulls against the oceans a bit more, forming ‘spring tides’. When this happens, the high tides are higher than normal, and the low tides are lower than normal. When the Moon is 90-degrees to the Earth and Sun (which we see as quarter Moons), the gravity of the Sun and Moon work against each other, causing lower than normal variations between high and low tide. These are ‘neap tides’, where the amplitude of the tides (meaning the difference between high and low tide) is the smallest.

To complicate things, the tides do not occur at the same times each day. Since the Moon orbits the Earth one time for every 29.5 times the Earth rotates on its own axis, it appears to gradually move from west to east each day, rising 50 minutes later from one day to the next (we discuss this in the next chapter as *retrograde motion*). Because of this, the tides also move in or out 50 minutes later each day. This complex dynamic, well known and described in Indigenous Knowledge systems, requires careful long-term observation.

On my second excursion to the Torres Strait Islands with Professor Nakata, I realised that both trips had taken place around the First Quarter Moon. When I asked him about this, he said, ‘Ah, you’re paying attention. Good!’ He did not explain why at first, allowing me time to reflect and consider the reason. Given his love for fishing, I figured the reason was due to the tides, which are driven by the phases of the Moon. Practically the entire trip revolved around that activity!

When I proffered this explanation, he nodded and said quarter Moons are the best time to fish. Full Moons are better for hunting large game, as you can more easily see them in the moonlight. Several other Elders confirmed this, explaining that the ideal times for fishing and hunting, and for planting gardens, all depend on the phases of the Moon, the time of day, the day of the month and the time of the year.

The reason the quarter Moons are the best time to go fishing is because the tidal amplitude is the smallest. This means silt and debris on the sea floor does not get churned up as much by the ebb and flow, making it easier for the fish to see the bait and for the fishers to see their prey. The fish also bite more. On Mer, large reefs extend outward from the island. Uncle William Bero explains that the fish are brought close to shore at high tide, then pushed back out to sea, beyond the reefs, at low tide. The neap tides are slow and sluggish. They keep the fish out at sea for several hours before the tide brings them closer to shore where they can feed. For this reason, the people call the tides at quarter Moons *Werir Meg*, 'hungry tide'.

The geography of the reefs also plays a part. The best place to fish during the First Quarter Moon is on the west side of the island, and on the east side during the Last Quarter (which has a slightly lower amplitude than tides at First Quarter). Uncle Meddy Kaigey says you will get the biggest haul of fish three days before and after First Quarter Moon. The ideal time of day is when the Moon is high in the sky; this is when the high tides come, bringing the hungry fish.

No two objects in the Universe orbit each other in a perfect circle. Sometimes the Moon is closer to Earth (*perigee*) and sometimes it is further away (*apogee*). The gravity of the Moon is higher at perigee, which pulls the oceans even more, and it also makes the Moon look bigger, which is often dubbed a 'supermoon'. If the Moon is in its New or Full phase when it is closer to Earth, those tidal amplitudes will be higher. And just as the Moon orbits in an ellipse around the Earth, so does the Earth around the Sun.

The Earth is closest to the Sun at *perihelion* and furthest at *aphelion*. Perihelion occurs each year in early January, about two weeks after the December solstice. The difference in distance between the Earth and the Sun at these extremes is 5 million kilometres! As you can imagine, this alters the influence of gravity on the ocean a fair bit. High tides that occur when the Earth is at perihelion are often dubbed *king tides*. These can be whoppers, causing large-scale flooding and significant damage to low-lying areas. If we

are unlucky enough for the Full or New Moon to be at perigee when we are closest to the Sun, we will experience the maximum effects with sometimes deadly results.

Torres Strait Islanders worked out these longer-term tidal cycles long ago. Uncle David Bosun teaches that the six highest (amplitude) tides of the year occur during the wet Kuki season from December to March. The six lowest (amplitude) tides occur during the Sager (dry season) from April to October. The people always know the king tides come in early January, and preparing for them is an increasingly essential activity, as the sea level gradually rises as the climate warms and ice melts. Some politicians and climate-change deniers may scoff, but for those who see it destroying their country, their livelihoods and their lives in real time, it's no joke.

Eclipses

In Euahlayi traditions of northern New South Wales, the sky is perceived as a dome that is held up by four wooden poles, to which ropes made from the bark of the kurrajong tree are attached. It is the duty of certain spirit ancestors to hold the ropes that hold up the sky-dome and keep it from falling. Long ago, Yhi, the Sun-woman, had a series of lovers. One day she fell in love with Bahloo the Moon-man. Bahloo did not reciprocate her feelings and rejected her advances. Yhi grew increasingly angry that he wanted nothing to do with her. She pursued him and he put space between them, moving further away from her each day.

In frustration, Yhi commanded the spirits holding up the dome of the sky not to let Bahloo escape the celestial realm and come down to the Earth. If he did, she threatened to cast down the spirits and cause the sky to fall, plunging the land into everlasting darkness. The cycle repeats, but Bahloo manages to escape—most of the time. To avoid Yhi and get to the Earth to carry out his duties, he is forced to sneak down past the spirits by disguising himself as an emu before dusk. But on rare occasions, Yhi captures and tries to kill Bahloo. She grabs him but he manages to struggle free, helped by the spirits. When this happens, Yhi goes completely dark. This is a solar eclipse.

This interaction in the narrative incorporates observation and deduction into complex levels of knowledge. The traditions explain the changing phases of the Moon and the apparent backwards west to east motion of the Moon each day. Bahloo's avoidance of Yhi is reflected in the apparent zigzag

motion the Moon makes as it moves back and forth to either side of the ecliptic over the course of a lunar month.

In 1922, a solar eclipse crossed the continent, from the Pilbara in Western Australia's north to the east coast. Aboriginal people at the Ooldea Mission, on the eastern edge of the Nullarbor Plain in South Australia, described the eclipse as the hand of the spirit-man Maamu-Waddi covering the Earth for the privacy of the Sun-woman and Moon-man while they were *guri-arra* ('husband and wife together'). Noongar people of Bremer Bay, Western Australia, teach that long ago the Sun and Moon fell to Earth and split it in half. This separated the lazy people, who live in a land on the other side of the Sun, from the rest of the community. Being lazy, they occasionally get bored and want to see what is happening in our world. They peer over the Sun, crowding around it and covering it with their hands. This causes the Sun to go dark but only for a short time, just long enough for each person to have a peek—hence the eclipse does not last long.

The description of an eclipse as the Moon covering the Sun demonstrates the long-term astronomical observations of First Peoples. As the Moon circles the Earth, there are times when these two bodies align perfectly with the Sun. This alignment is called *syzygy*. The Sun is 400 times wider than the Moon but is also 400 times further away. This coincidental ratio means the angular diameter of the Sun and Moon are about the same: half a degree.

When the Sun, Moon and Earth are in syzygy, the Moon casts a shadow on the Earth. Those in that shadow experience a solar eclipse. If we see the Moon completely cover the Sun, it is a *total solar eclipse*. Otherwise, it is a *partial eclipse*. The shadow moves quickly across the Earth's surface at speeds that can exceed 3000 kilometres per hour so the maximum length of time we see the Moon completely cover the Sun is about seven and a half minutes. It is usually much shorter.

From any given location on Earth, a total solar eclipse is seen only once every few hundred years, lasting just a few minutes. The rarity of these events shows the power of orality, which commits these short transient events to memory and passes them down over several generations. It is also important to note that a solar eclipse always occurs during a New Moon. This is when the Moon appears to 'die' and we are unable to see it—meaning Aboriginal people long ago were aware of the Moon's location in the sky even when it was not visible.

To give this some context, it is important to see where this discovery sits

within scholarship in the history and philosophy of Western science. According to historians of science, solar eclipses were not known to be caused by the Moon covering the Sun until the fifth century BCE, when it was ‘discovered’ by the pre-Socratic Greek philosophers Anaxagoras and Empedocles.

How far back these eclipse traditions stretch in time is not known, but observers from Galiwin’ku (Elcho Island) have experienced only four total solar eclipses in the last two and a half millennia. The last one occurred in the year 1188 CE. When the Galiwin’ku tradition was published by ethnographer W. Lloyd Warner in 1937, it had been almost 750 years since a total solar eclipse was last seen from that place. Of course, numerous partial eclipses were visible over that time, and people did travel and communicate with others from regions where total eclipses would have been visible. The point is that total solar eclipses are not common occurrences and a partial eclipse can pass without recognition unless people are closely watching the Sun while it is happening.

If the Sun, Earth, and Moon are in syzygy in that order, the Earth casts a much larger shadow than the Moon. As the Moon moves into the shadow of the Earth, we see it slowly fade until it turns an eerie dark red. This is a lunar eclipse. Lunar eclipses and their deep red colour are often associated with blood and death, and ceremonies or raids relating to this.

In the Torres Strait Islands, eclipses were traditionally associated with a very special ceremony. David Bosun explains that boys who reach puberty are taken to the kwod for seven years of instruction before initiation. As a final test, initiates are required to collect skulls from neighbouring islands during a raid and bring them to a sacred ground. Islanders believe that the skulls of enemies contain powerful magic, a belief shared by cultures from Australia to Europe. If the skull belonged to a powerful sorcerer or skilled hunter, the person taking it will obtain their powers.

For initiated men, the raids were conducted during a lunar eclipse. On Mua, an eclipse of the Moon is called *Merlpal maru pathanu* in the Maluililgal dialect, meaning ‘the ghost has taken the spirit of the Moon’. On Boigu, to the far north of the Torres Strait, an eclipse is described as *Meripal kulkan patan*, meaning ‘blood covering the Moon’.

As the Moon began to darken, men would perform the sacred ceremony to identify the direction of the incoming attackers. They donned the *Mayngu dhoeri*, a special lunar eclipse headdress, and began reciting the names of all

the islands of the Straits. The island named when the Moon emerged from the eclipse was believed to be the homeland of the approaching raiders. The men prepared for war while the women took the children and sought refuge in the jungles and forests. These ceremonies were well planned, informed by the Zugubau Mabaig. He knew in advance when the eclipse would occur, through careful observation of the Moon's position relative to the path of the Sun.

Lunar eclipses always occur when the Moon is full and when its path crosses the path of the Sun (ecliptic). Careful observers can note a few important characteristics that could enable them to predict such an event, which can be measured by one of two general methods: the less precise 'eclipse season' and the more precise Saros cycle.

The ancient Mesopotamians are credited with figuring out the Saros cycle—the approximately 18-year cycle where the Earth, Moon and Sun line up to produce an eclipse—around the year 700 BCE. Some historians give credit to the pre-Socratic Greek philosopher, Thales of Miletus, for being the first to predict a solar eclipse. The eclipse of 585 BCE allegedly occurred during a battle between the Medes and the Lydians, who saw it as an omen and concluded the battle with a truce. This was part of a narrative recorded by Herodotus, and some scholars have argued against the veracity of this event.

It is currently unclear exactly how the Zugubau Mabaig predicted lunar eclipses or how far back this practice goes in time, as this information was shared at the final stages of this book's development. This is a topic of ongoing discussion with the community, but the advanced preparation of an important ceremony based solely on the occurrence of this event tells us this was a skill they possessed.

Cusps

I feel an almost spiritual connection when watching the Sun set. This is my favourite time of day, and I especially love it when a crescent Moon is visible in the eastern sky. I never really paid much attention to the way the crescent Moon looked, except to note that sometimes the tips of the crescent pointed upwards in the sky. I always referred to this as the 'Cheshire Grin' from the film *Alice in Wonderland*—as the Cheshire Cat gradually faded into darkness, the last thing you could see was his eerily toothy smile. It was not until sitting with Elders on Mer that I understood the orientation of the

crescent Moon has a practical application that goes beyond childhood memories.

Merlpal Maru Pathanu **(the ghost has taken the spirit of the Moon), by David Bosun (2007)**

The pointed tips of the crescent Moon are called *cusps*. Their angle in the sky is not random, despite a great many artists orientating them randomly in paintings and drawings. The cusps always point directly away from the Sun. The Elders teach that the Sun changes position throughout the year, moving in a path higher in the sky over summer months and lower over winter. This change in the angle of the ecliptic is due to our planet orbiting the Sun while tilted on its axis by 23.5 degrees. The Moon orbits the Earth in roughly the same plane (it is off by a few degrees), meaning that the angle of the Moon's cusps with respect to the horizon will change throughout the year. Sometimes the cusps will point upwards at dusk, while other times the Moon is tilted and the cusps point off at an angle.

I first learned about this from Uncle Segar Passi. As he was explaining how one observes the Sun's position throughout the year to predict seasonal change, I noticed two nearly identical paintings of the Moon on his wall. They both featured the crescent Moon after sunset, lying low in the western sky. When I looked more closely, I could see they were not the same. Their distinct differences indicated something important. One shows the Moon with the cusps pointing upwards. Surrounding it are puffy cumulus clouds and the water below looks choppy, with waves cresting, poorly reflecting the moonlight.

In the other painting, the Moon is tilted at an angle and is surrounded by thin cirrus clouds. The Moon's reflection appears more clearly and brightly in the calm waters below. As Uncle Segar explained, each colour, each brushstroke, each element has meaning and significance. In his soft voice, he signalled their meaning: 'Every month there is a New Moon at a different angle. Did you ever notice this?'

He explained that the orientation of the crescent Moon (*kerkar meb*) each month can tell you about the changing seasons if you look at the angle of its tilt. The cusps point upwards (*meb metalug em*) during the dry Sager season. At this time, you will often see large cumulus clouds in the evening sky and the water below is rough and choppy. When the Moon cusps are tilted at an angle (*meb uag em*), you will find that it is often surrounded by cirrus clouds, and the water below is calm and brightly reflecting the shining Moon. This occurs during the Koki (wet monsoon season).

This seemed counterintuitive to me. I figured the puffy clouds and choppy waters would be more common in the stormy wet season than the calm dry season. But that was simply a reflection of my ignorance about weather

conditions in the region. Uncle Segar pointed to the painting: ‘If the water looks rough and the Moon is pointed up, you know the winds will die down and the next day the water will be fine. But when the Moon is tilted, the water is still but bad weather is coming soon.’

The Moon cusps pointing upwards tends to occur in September and October. This is the Naiger season, when the weather is fine, temperatures are high, and the south-east winds begin to drop, making the air very still. The Moon tends to be tilted during the Koki from January to March. Uncle Segar reckons the Moon looks like a dish. When it is upwards, it holds the water and none of it reaches the ground. But when it is tilted, it tips the water out onto the Earth.

This is remarkably similar to Lakota traditions of the North American Midwest. When the cusps of *Haŋhépiwi* (the Moon) are pointed upwards, rainfall is at its lowest. This occurs during the winter months of January and February when it is called Dry Moon. If the crescent Moon is tilted, water pours out onto the land as rain. It is called the Wet Moon and occurs in the summer months when rainfall is highest. The Lakota description of the Moon’s angles may be the same, but the time of year when the cusps point upwards or are tilted differ because of the viewing point on the Earth: Lakota Country is at a latitude of 45 degrees North, while Mer is at a latitude of 10 degrees South.

Haloes

As mentioned at the start of this chapter, the sight of a ring around the Moon is known globally as a sign that rain is on the way. From Alaska to Zimbabwe, rings around the Sun and Moon are used as an important weather forecaster. Aboriginal people of Tasmania teach that a ring around the Moon is a sure sign of bad weather and plenty of wind. The same applies in the Torres Strait. This ring is formed by ice crystals in thin cirrus or cirrostratus clouds high in the atmosphere, which Western astronomers call a halo. The crystals refract the incoming moonlight. Due to their geometry, they form haloes that are 22 degrees wide, and sometimes double this. These clouds and ice crystals develop in low fronts, which tend to bring rain.

But, as always, it is a bit more complex than that. If you want to know when it will rain and how much, you need to ask the right questions: What does the halo look like? How many haloes are visible? Can you see any stars

inside the halo? How many? What are the animals and insects doing? Is it windy or calm when you see it? What colour is it? How bright is it?

Forecasting weather is an art and a science. Forecasting the type, time, duration and amount of rain is challenging. While not an *exact* science, it is highly effective if you know how to read what the Moon is telling you. This makes the difference between a poorly informed amateur and a skilled meteorologist. In the Torres Strait Islands, Elders teach a great many things about haloes. Firstly, the ring signifies the Moon-man building a hut to keep himself dry from the approaching rain. In the western islands, a lunar halo is called *kubwai*, while in the eastern islands it is called *susri*.

On Mer, susri are used to predict wind and rain. One must observe other aspects of the environment to effectively forecast when the rain will come. Uncle Ron Day, a Komet Elder, explains that the size of a halo can tell you how soon rain can be expected. If the susri is a larger 44-degree halo, then rain will come sooner. It can also warn that bad news is coming, perhaps the illness or death of a loved one. If the susri is smaller, the sad news will come sooner. Another Elder mentioned that if cockroaches are flying about when the halo is visible, rain is imminent.

The Torres Strait is not the only place where the people perceive the Moon-man building a home to keep himself dry. A nearly identical view is found in the Euahlayi traditions of northern New South Wales about Bahloo. A Euahlayi Elder (who chose to remain anonymous) explained to Bob Fuller what her father taught her about a ring encircling Bahloo:

> Hullo! Going to be rain. Bahloo building a house to keep himself dry. If there is a ring around it, count the stars in the ring: two, three or seven. If there are three stars, there will be rain on the third day.

The Elder explained that the cultural meaning of a halo refers to the actions of a spiritual Clever Man who can bring rain. He is represented by the bright red star Aldebaran and is responsible for keeping the young uninitiated boys, represented by the stars in Orion’s belt and scabbard, away from the beautiful young girls of the Pleiades. The Clever Man constructs a ceremonial ground and the dust kicked up by dancers forms a ring around the Moon. This dust creates clouds, which bring rain. Just as Bahloo builds a house to keep himself dry, the Clever Man shelters himself in his *gunya* (hut). You can see the gunya as the V-shaped star cluster called the Hyades. The Elder explained that the Moon can have two rings around it: one closer and one further away

(the 22-degree and 44-degree haloes).

In Tiwi traditions, lunar haloes are an important component of the annual Kulama ceremony. The ceremony is performed towards the end of the *Jamutakari* (monsoon season), around late March to early April. It is signalled by the appearance of a golden ring around the Moon. The circular shape of the *milimika* (ceremonial dancing ground) represents the halo, which is seen as the participation of the Moon-man. The ceremony takes place over three days and nights. It is a period of initiation for young men and the time for gardeners to harvest the kulama yam (*Dioscorea bulbifera*). This yam is normally poisonous but Tiwi Islanders prepare it using a complex detoxification process to render it edible, which takes three days.

Gedge Togia

The legal fiction of *terra nullius* (‘a land belonging to no one’) meant that Aboriginal and Torres Strait Islander peoples had no legal right to their land, through either personal or communal ownership. The position of the Australian colony was that Aboriginal and Torres Strait Islander peoples had no concept of land ownership, thus giving total ownership of the continent to the British Crown.

In 1982, five Meriam people—Edward Koiki Mabo, David Passi, Sam Passi, James Rice and Celuia Mapo Sale—filed legal action in the High Court against the State of Queensland and the Commonwealth of Australia, challenging the concept of terra nullius and fighting for what would become the legislation known as *The Native Title Act 1993*. Their legal challenge focused on traditional ownership of land on Mer, Dauar and Waier.

Meriam families have definitive property boundaries and communal concepts of land ownership that extend to the sea and sky. You can see evidence of this today in the stone wall fish traps, or *sai,* in the water that extend from the shoreline out onto the reef. These are used to funnel fish to small enclosures for capture as the tides recede and serve as property boundaries. They are still clearly visible all around the island today.

After a decade of gruelling legal battles and lawsuits against the Queensland government, the Meriam people won their case and were granted land rights on 3 June 1992. Six out of seven judges of the High Court ruled that ‘the Meriam people are entitled as against the whole world to possession, occupation, use and enjoyment of the lands of the Murray Islands’. Every

year on 3 June, Australia celebrates Mabo Day, marking the decision by the High Court and honouring Uncle Koiki Mabo for leading the charge. Unfortunately, Uncle Koiki passed away in January 1992, six months before the successful ruling.

The Mabo decision established a precedent for native title, but this ruling did not necessarily extend to sea rights. In the early 2000s, a group of Torres Strait Islanders launched a legal battle for commercial sea rights. Uncle Alo Tapim was one of the defendants and explained how government lawyers argued against the declaration by claiming each island was a separate enclave with no connection to one another. This legal position stood in the face of the fact that Torres Strait Islanders have a long history of cultural, linguistic and family connections across the Strait and with Papua New Guinea and mainland Australia.

During the proceedings, the people were required to prove their longstanding connections in court. One crucial piece of evidence was a traditional Moon Dance. *Gedge Togia* is a sacred spiritual dance (*kab kar*) of the Meriam people, linking Mer with the island of Mabuyag. The link is established through the lyrics and the fact that they are sung in two languages. The lyrics consist of only three words: '*Gedge togia, milpalnuka'*. *Gedge Togia* means 'rising over home' in the Meriam Mir language, and *milpalnuka* refers to the Moon in the Mabuyag dialect of the Kala Lagau Ya language. The two languages are distinct but share approximately 40 per cent of the same vocabulary.

The two islands lie almost due east and west of one another, separated by 200 kilometres of ocean. The dancers hold two handles with a Moon at each end. They can include a full and/or crescent Moon. As Meriam people sail home from Mabuyag they will see the Full Moon rising over Mer at dusk or the crescent Moon rising over their home at dawn.

During legal proceedings in the mid-2000s, a judge travelled to Mer and observed testimony presented by the Elders. Uncle Alo Tapim sat before the judge, hooked up to cameras and microphones. He sang the song, explained the dance and elaborated upon the traditional dress worn by the dancers, describing the importance and relevance of the dance to Meriam people. He proved the connection between Mabuyag and Mer through a multilingual song that signified travel for trade and family connection.

The Islanders won their battle for sea rights.

CHAPTER 4

The Wandering Stars

‘The planets come straight across like you and I doing a walk … up and down, walking backwards, forwards.’

—Yidumduma Bill Harney, Senior Wardaman Elder

In 2018, the community on Mer celebrated the arrival of a new telescope for Tagai State College. The students, eager to learn, brought their families, which included several Elders. Each night I hosted a different year group so the kids would have an opportunity to share their curiosity about the stars with their families, who inspired their love of the cosmos. The experience for both parties was exciting, but for different reasons.

Most astrophysicists spend their time looking at computer screens when conducting observations with professional telescopes. They are connected to complex computers armed with highly sensitive equipment. In all actuality, looking through a telescope with your own eyes is something you do only during outreach activities. These activities tend to occur on university campuses where dark skies are not a common reality, as most astronomers live and work in major cities. You would think that astrophysicists would be accustomed to seeing beautifully dark skies, but this is often not the case. However, it *is* normal for people on Mer. One Elder explained the importance of a concept called *purut*, a time for family to sleep on the beach under the clear skies where they tell star stories.

On the remote island, the view of the stars is breathtaking. You can see many things with the unaided eye there that you cannot see at all from the city, even with a telescope. The clear skies over Mer allow telescope users to see much fainter objects than city dwellers. Unfortunately, most communities do not have telescopes, and most Elders have never looked through one. A trio of children gathered around the telescope, which was focused on Saturn. After a few excited minutes, one child pulled his grandmother over. ‘Holy

$#!%, look at that!' she exclaimed. This was the first time in her 60-odd years she had seen the rings of Saturn.

The kids turned to me and pointed to the west. 'Do you know what that star is?' they asked. I nodded and asked if they knew. One boy pointed and said, 'That's *Iluel*, the Evening Star. I think you call it Venus. In the morning we call it *Gerger Neseur*.' The children on Mer know the stars. They know the Meriam names and most know the Western names, and they know what they mean. It is a perfect illustration of living knowledge. Elders explain that Iluel and Gerger Neseur are the same object, as you will never see them in the morning and the evening on the same day.

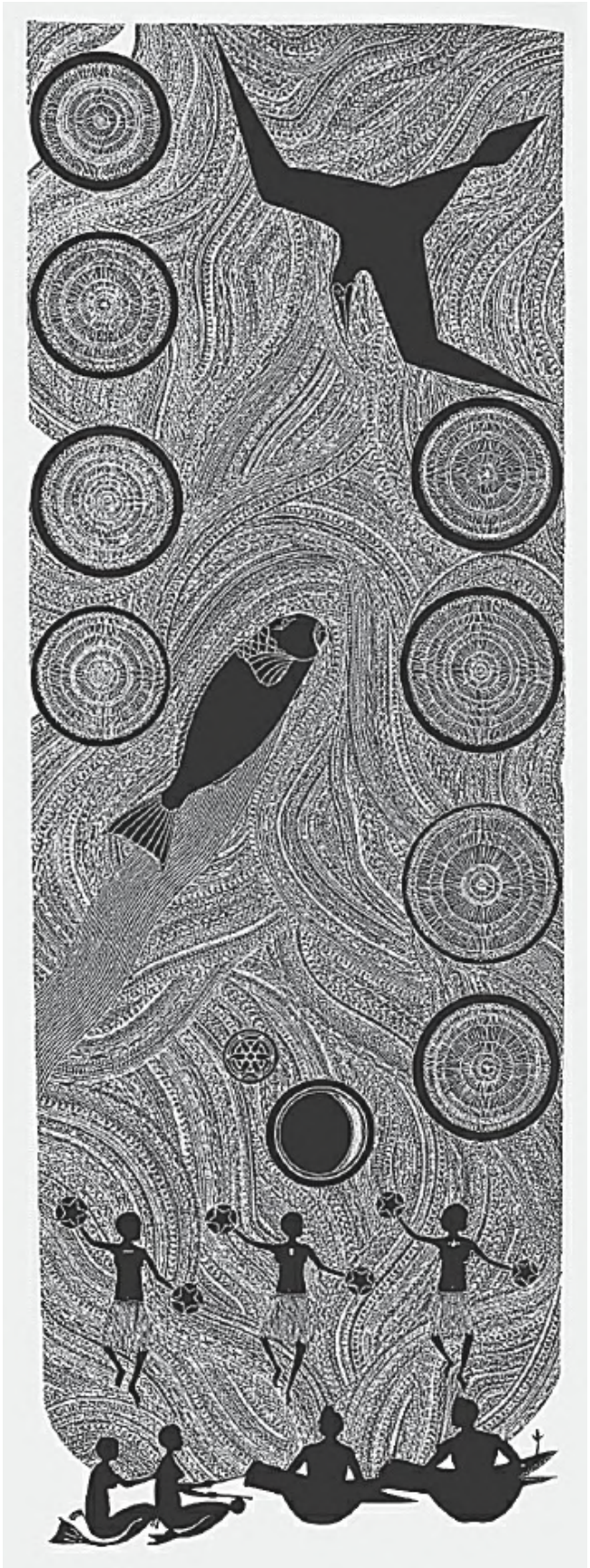
Iluel relates to a Moon story from the island of Erub, north of Mer, that tells of a young Meuram man and Saisarem woman. These are two of the four main clan groups on Erub, with Meuram being in the north-east of the island and Saisarem being in the north-west. This story was shared by Erub Elder Kapua Gutchen Snr and is featured in the work of Meuram artist Daniel O'Shane. Iluel is a beautiful woman whose lover is Meb, the mischievous Moon-man. Their relationship is disrupted by constant *atkit* (jealousy): Meb is jealous of Iluel's relationship with *Lim* (the Sun), and Iluel is suspicious of Meb's relationship with her sisters. Meb attempts to take Iluel back to his homeland, but their jealousy is too much.

The lovers join each other once a month when Iluel appears near Meb in the evening sky. Meb is always in a crescent phase and is visible in the north-western skies, over Iluel's clan area on Erub. As days pass, they drift away from one another. Meb waxes until he appears in full form in the east at dusk, over his home Country. To this day, Erub Islanders refer to the waxing crescent Moon as *Atkit Meb*, 'jealous Moon'.

The story explains the relative motions of the Sun, Moon and Venus. Venus is always seen near the Sun as the planet's orbit is closer to the Sun than Earth, explaining Meb's jealousy of Iluel's relationship with Lim. They are only visible together when Venus is near the Sun, and they come so close it almost looks as though they embrace. But Iluel becomes jealous of Meb and his relationship with her sisters—Mercury, Mars, Jupiter and Saturn—as they sometimes brush past or move behind Meb. This tradition explains the movements of these celestial bodies around the Solar System as we see them. It is also reminiscent of ancient Babylonian traditions of *Ishtar* (Venus), a fickle goddess who flirted with Shamash, the Sun-god. She constantly moves around and brushes up against Shamash as she pursues him across the sky

and through the underworld.

Venus is arguably the most prominently featured and commonly described planet in Indigenous traditions, being the third-brightest object in the sky after the Sun and Moon. The planet's movements relative to the stars in the zodiac, the Moon, the Sun, the other planets, its changing brightness and its position on the horizon as it moves back and forth from a Morning Star to an Evening Star all have special significance. This is built on millennia of careful observation, but also on the Indigenous mathematical frameworks that are used to work out its complex but predictable cycles. Traditional knowledge of the planets is diverse and complex, but still poorly understood outside of those communities.



***Iluel Kab* (Evening Star Dance), by Daniel O'Shane (2014). (Courtesy of Daniel O'Shane and Canopy Arts)**

Planet knowledge

The word *planet* comes from the Greek *planetes*, meaning 'wanderer'. We learn from Indigenous Knowledges that there are five of these wandering stars, and each of them works by its own set of rules. Two of them do not venture far from the Sun in the sky, being visible only at dusk, dawn or during the day, but never in the middle of the night. The other three may be visible at dusk, dawn or in the middle of the night.

Some planets spend very little time in the sky, while others move slowly from horizon to horizon, night after night. They all change in brightness over time, and they will often pass near stars in the zodiac, the Moon or other planets. This a phenomenon that Western astronomers call a *conjunction*. These planets have thousands of traditional names but are known to Western science by their Roman names: Mercury, Venus, Mars, Jupiter and Saturn.

Mercury, the closest planet to the Sun, moves fast. The Ancient Romans referred to it as fleet-footed, naming it after their swift messenger god. Mercury can be seen as a Morning Star and an Evening Star but is not as bright as Venus, nor does it reach as high in the sky. The Ancient Greeks believed that Mercury was two separate beings: Hermes when it was visible in the evening, and Apollo when it was visible in the morning.

Mercury is invisible to us much of the time, appearing low in the morning sky for a couple of weeks before disappearing for a month and a half. It reappears low in the evening sky for another fortnight before disappearing again. In total, it takes 116 days for it to come back to the same position in the sky (this is its synodic period). It rarely appears very high above the horizon at dusk or dawn, only stretching out about 30 degrees away from the Sun. The term Western astronomers use for the maximum angular distance Mercury or Venus will be seen from the Sun is *elongation*.

Venus has similar characteristics to Mercury: it never ventures far from the Sun, being closer to the Sun than the Earth, and will also appear as a Morning or Evening Star. Neither planet will ever be seen in the sky opposite the Sun. Since Venus reaches a much greater elongation (about 46 degrees), it can appear more prominently in the sky at dusk or dawn.

The planets further away from the Sun than the Earth are Mars, Jupiter and Saturn. They can be visible all along the path of the zodiac, day or night. They move more slowly than Mercury and Venus, with Saturn being the slowest as it crawls around the Sun, completing a full orbit in just under 30 Earth years. Ancient cultures in Europe and Mesopotamia referred to Saturn as a grandfather for this reason.

The properties of the planets are important in understanding the role they play in culture and how they are conceptualised. Some are brighter than the fixed stars, while others are fainter. They all wander in their own unique path and have distinct colours. Venus and Mercury are known for their brightness, while Saturn is known for its slightly yellowy colour. Mars and Jupiter are associated with ruddy colours. Anmatyerre people of Australia's Central Desert describe Mars as *lherrm-penh*, meaning 'something that has been burnt in flames' and Kokatha traditions of the Great Victoria Desert associate Mars with *Kogolongo*, the red-tailed black cockatoo.

Curiously, Kokatha people also link Kogolongo with the star Antares. Just like Mars, Antares is bright, red and lies within the zodiac. Mars occasionally passes close by the star for a period of time, with the two fighting for dominance in the night sky. This rivalry is reflected in star traditions around the world. 'Antares' is considered the 'anti-Ares', or rival of Ares—the Greek god of war. Mars is the Roman god of war. This rivalry has been a point of confusion for many scholars, who seem to conflate the two objects. This is something we will discuss further in Chapter 7: The Variable Stars.

Recognising and understanding the rules of planetary motions is not an easy task. It requires careful observation over several years, detailing records that can be maintained and passed down to new generations accurately, and mathematical systems must be developed to calculate, measure and predict these movements, as well as synchronise them together into multifaceted, long-term calendars. We know that First Peoples achieved this. Let's look at how.

Retrograde motion

The planets orbit the Sun in roughly the same plane, varying by approximately 8 degrees either side of the ecliptic. This plane, called the zodiac by Westerners, is generally described as a road or pathway for the ancestor spirits in the cultures of First Peoples. In some cultures, this pathway

is a road to the land of the dead on which spirits travel to the afterworld.

Kokatha Elders explain that Jupiter and Venus follow one another along the ‘Dream road’. In Lakota traditions, the path of the zodiac is called *Cạŋku Wiċaŋhpi Omani*, literally translating to ‘Road (on which the) Stars Travel’. Uncle Yidumduma Bill Harney refers to the path of the zodiac as *Yondorrin*. He teaches how this celestial Dreaming track serves as a road over which the ‘old spirits’ (planets) walk during their travels: ‘Planets making the pathway! Travelling routes, a pathway you could call it, like a highway! The Dreaming Track in the sky! If you say to me, can we go somewhere? I say, “Yes, follow me and I’ll take you straight there!” The track is straight across Country. Yondorrin shows how.’

This chapter began with a quote from Uncle Yidumduma about the motions of the planets and how they move in peculiar ways. He described how they move along the path of Yondorrin ‘like you and I doing a walk … up and down, walking backwards, forwards’. Like any of us walking down the street, we pass each other, stop, backtrack or walk on either side of the footpath as others pass by. Maybe we pause to gaze in a shop window, step back to grab something we dropped or wait up for a friend so we can walk together for a while before continuing our own journey.

The planets do the same thing, and First Peoples of the world describe this phenomenon in similar terms. Western astronomers call it *retrograde motion*. Derived from the Latin word *retrogradus*, meaning ‘backwards step’, it describes the apparent backward movement of a planet among the stars. However, it is an optical illusion, a visual effect due to the relative positions of the planets and their different orbital speeds. All the planets in the Solar System spend periods of time in retrograde. Why?

The Earth orbits the Sun faster than Mars because it is closer to the star. As we zoom along our orbit, every 26 months or so we come up from behind Mars, moving past the point where Mars is opposite the Sun in the sky. This causes the Red Planet to appear in different places with respect to the background stars, making it look as though it is moving backwards. This change in Mars’ motion through retrograde lasts 72 days, or about ten weeks.

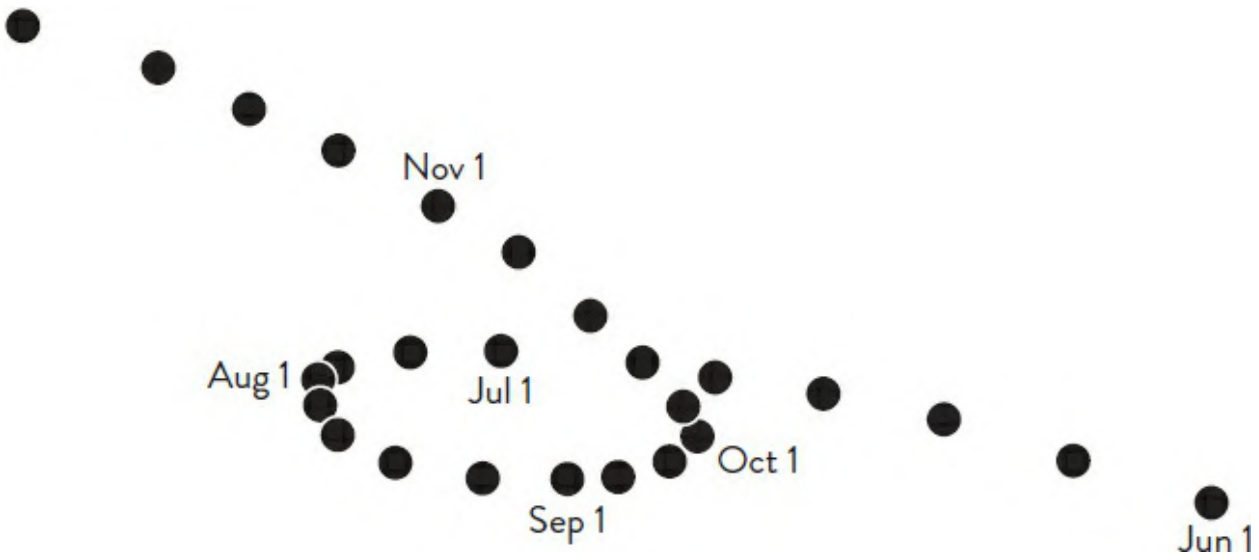
In the Néhinaw Nation, one of Canada’s largest First Nations, the phenomenon of retrograde motion is well known. Wilfred Buck, an Ininew Elder from Manitoba and a star knowledge expert, explains it as follows:

> Because Earth orbits the Sun faster than Mars, at certain times Earth passes Mars, [and] it looks like Mars does a circle in the sky. Retrograde motion. So they call it *kitom pampaniw*—‘circles

back'. Another name is *mooswa acak*—'moose spirit'. Because when a moose is startled, it'll run in a huge circle, and then continue on its way.

For decades, astronomers have been trying to explain why some of the many traditions about the Seven Sisters (Pleiades) describe the number of sisters to be seven, even though you usually see only six stars. Explanations range from their visibility changing with respect to atmospheric conditions, the variability of the seventh sister, Pleione, and even the possibility that these traditions share a common source 100,000 years ago, when Atlas and Pleione were far enough apart to be more easily resolved as two distinct stars rather than one.

Noongar Elder Dr Noel Nannup explains one reason the Pleiades is usually associated with six stars but is sometimes associated with seven:



The retrograde motion of Mars in 2003, when it reached its closest approach to the Earth in 60,000 years

When it comes to the story of the Seven [Sisters], there are really only six, as the seventh is one of the planets, and the planets go the opposite way. This is why you will always hear the desert people saying the seventh sister is coming home … You will see the seventh sister getting closer and closer, but then she will go past … And when that happens, people will say she has visited her sisters.

Because the Pleiades is within the path of the zodiac, planets in retrograde motion will occasionally move either through, or close by, the star cluster.

But the planet doesn’t stay for long, which is why we usually only see six stars in the Pleiades. In some parts of the world, there are traditions that describe well over seven stars in the Pleiades. This includes Māori astronomy, which names nine.

Planetary conjunctions

Occasionally, planets can come close together as they journey across the cosmos on the celestial road, like two friends briefly meeting for a walk. When this happens, astronomers call it a *conjunction*. There are many interesting ways this is conceptualised by cultures across the world. In western Greenland, Inuit Elders describe planetary conjunctions as celestial women who visit each other. Ancient cultures saw conjunctions as omens of war, famine and general disaster. Others saw it as a positive sign. Some scholars suggest the Magi following the Star of Bethlehem were guided by the conjunction of Venus and Jupiter when the planets were just one-tenth of a degree apart.

In December 2020, after experiencing months of hard lockdown from Covid-19 in Melbourne, my partner and I decided to grab a telescope and book a couple of nights in a small farmhouse in the country town of Yea, Victoria. During those two nights, a rare and extremely close conjunction of Jupiter and Saturn was visible in the evening sky. The planetary duo reached their closest approach of just one-tenth of a degree on 21 December—the day of the summer solstice. For an astronomer, it was a double whammy of cosmic excitement. The last time these two planets appeared this close together in the sky was in 1623, around the time Galileo was describing the aurora. Because the conjunction was so close to 25 December, and because some biblical scholars suggested that the Star of Bethlehem was actually a close conjunction of two planets, people in the media referred to it as the ‘Christmas Star’.

On 20 December we settled in and set up the telescope to have a peek. The two planets appeared as a bright double star in the evening sky: an amazing sight. Through the telescope, you could see both in the same field of view. The moons of Jupiter seemed to overlap those of Saturn, and you gained a new appreciation for how far out the moons of each planet extend. The next evening, however, the view was obscured by thick cloud cover. Astronomers have an adage: if you want to guarantee cloudy skies, bring a telescope.

In the lead-up, Jupiter and Saturn drew closer together each night. Commentators around the world noted that they seemed like eyes in the sky. Coincidentally, some First Peoples held a similar view. Euahlayi people of northern New South Wales describe the conjunction of Venus and Mars as the eyes of Buwadjarr, the supreme creation ancestor known as the 'All Father'. This cosmic event has special significance and is linked to ceremony.

A few years back, Bob Fuller worked with Uncle Ghillar Michael Anderson and other Elders to document Kamilaroi and Euahlayi star knowledge. An Elder (who wishes to remain anonymous) explained the relationship between the two planets, how their colours are represented on the land, and how their conjunction is related to the eyes of the 'All Father': 'During the day, the eyes of Maliyan [the eaglehawk] are the eyes of Buwadjarr. During the night, Maliyan's eyes are Venus and Mars, which become the eyes of Buwadjarr. One is red [Mars], and one is blue and green [Venus].'

Two stones are brought together during a special ceremony held near Quilpie, 600 kilometres to the north-west near Goodooga in western Queensland. The Euahlayi bring a green and blue opal, representing Venus, when they meet the local Maranganji people, who bring a red stone signifying Mars. The travel route to this ceremonial site is part of a Songline that is mapped out in Chapter 9: The Navigational Stars.

Zodiacal light

A common theme in Indigenous astronomies around the world is celestial objects symbolising eyes. The stars represent the eyes of Mirabooka, a man who assisted the All Father to look over the people, as taught in Quandamooka traditions around Moreton Bay in south-eastern Queensland. The two Pointer stars (Alpha and Beta Centauri) represent the eyes of the celestial llama in Incan traditions. Across much of northern Australia, shooting stars are seen as the fiery eyes of the Rainbow Serpent. As seen in the previous section, the planets, too, can be perceived as eyes.

Aboriginal people of the Hamilton and Georgina rivers in Queensland refer to Venus as *Mumungooma*, meaning 'big-eye'. They describe Venus as a place of fertile grasslands and abundant seeds for making flour. The people of Mumungooma have no water but if they grow thirsty, they can travel to Earth by ropes that hang from it. A number of First Peoples' traditions around the

world mention white ropes connecting Venus to the Earth, by which people can travel to and from the celestial realm. These ropes are represented by a white glow that appears in the west after dusk and in the east before dawn. Astronomers call it *zodiacal light*, as this band of light appears along the zodiac.

In Yolŋu traditions of Arnhem Land in the Northern Territory, this light relates to the *Baṉumbirr* ceremony. This is a reference to Venus as the Morning Star. Baṉumbirr is a creation ancestor that guides the spirits of the recently deceased to Burralku, the island of the dead. She led the very first people to this Country, flying overhead and naming the features of the landscape as she passed over. This formed part of a longer Songline or travel route across the land, connecting sacred places and committing the information to memory though song. Because of her brightness, she was asked by fishers to join them in the morning but refused as she was terrified of drowning. Her sisters devised a solution by tying her to a rope to prevent her from drowning. The rope tied to her explains why she never ventures far into the sky at dusk or dawn.

The timing of the ceremony is related to the transition of Venus from an Evening Star to a Morning Star and includes the use of a Morning Star Pole. This is a long wooden pole decorated with important motifs from which white feathered strings hang down. The strings represent the rope the sisters tied to Baṉumbirr. During the ceremony, the Evening Star remains hidden until a couple of hours before dawn, when she pulls the planet up by the feathered rope. When the Sun comes up, the rope is hidden until the following evening. You can see the faint white rope in the sky as the zodiacal light.

In Western science, zodiacal light is the faint ref lection of the Sun’s light by dust in the plane of the Solar System. The brightness of the zodiacal light is lower at points in the sky further away from the Sun. It appears as a tall, triangle-shaped area of diffuse white light extending up into the sky. First Peoples linked Venus to the glow of zodiacal light through careful observation. Venus does not stray far from the Sun, so it’s always visible in the band of this light. Because zodiacal light is brightest near the Sun, it is visible only for a short time after dusk or before dawn, when Venus appears as a Morning or Evening Star. It looks as though Venus is attached to the Sun by a white rope.

To be able to see it requires very dark skies, but when your eyes adjust to

the growing darkness it slowly emerges. The first time I remember seeing it was when I was on Mer. I was admiring the sky after sunset, and it looked to me like a faint glowing triangle that petered off into darkness as it reached high into the sky. I was surprised I could make it out so clearly! It was a gorgeous sight.

The very next day Komet Elders Bob and Meddy Kaigey sat down to teach me about natural markers that indicate the coming monsoon. Uncle Meddy explained that the blue sky is whiter lower on the horizon where the Sun sets, with a column of white light extending upwards. He placed his hands close together with his fingertips touching and his palms separated by a few centimetres, simulating a tall triangle shape. He explained that when the faint white light stretches straight up into the sky, it tells the people that the rains of the monsoon season will start falling within the next fortnight. It is then time to begin planting bananas and sugarcane. Uncle Meddy said his father taught him this knowledge. He never referred to it as zodiacal light but that is exactly what he was describing.

From the Torres Strait, you will see the ecliptic extend vertically from the horizon straight up to the top of the sky after sunset only twice per year: in early July and mid-November. Research shows the zodiacal light is easiest to see in spring in either hemisphere. This corresponds to mid-November in the Torres Strait, when gardeners begin planting crops. The monsoon rains start falling in late November and early December, kicking off full throttle by the end of the year.

Cycles of Venus

The Ba̱numbirr ceremony may describe the presence of zodiacal light, but it focuses on a special astronomical event that requires careful, long-term observation and accurate mathematical records. The timing of the ceremony is directly related to the *synodic period* of Venus—what Western astronomers define as the time it takes for a celestial object to return to its original position in the sky. The ceremony requires planning and takes place at a specific time looking in a certain direction.

Ba̱numbirr is connected to creation and death. She guides the spirits of the recently deceased to her home: Burralku, the island of the dead. Even though she represents Venus, the planet is also seen as an object that she controls. The Yolŋu describe the Evening Star disappearing for a period of time before

rising at dawn. Before sunrise, the woman releases the Morning Star, which slowly ascends into the sky, attached to the long rope she holds. Baṉumbirr climbs up a pandanus tree as she rises, surveying the Country she will visit. As the Morning Star rises, it pauses over each of the clan groups, which are represented by the motifs on the Morning Star Pole. As the Sun emerges, Baṉumbirr pulls the Morning Star back using the pandanus string, where it disappears until the next day.

The ceremony, which is still practised today, links to the funeral process. These traditions were maintained by Gurruwiwi, a Yolŋu leader from Galiwin'ku (Elcho Island) in north-east Arnhem Land whose father was the last remaining custodian of the Baṉumbirr tradition.

> It was very important to my father that I know the story of Baṉumbirr. He was the last from all the clans who knew the stories so he was custodian of the Baṉumbirr Pole. He taught me that Baṉumbirr was the brightest star in the sky. He taught me that it symbolised the cycle of life and the metamorphosis that occurs within it.

Gurruwiwi was the primary source of knowledge about this sacred ceremony and made national news in 2015 for travelling over 3000 kilometres to perform the traditional *Lunggurrma* (North Wind) dance with his granddaughter at her Year 10 graduation at Worawa Aboriginal College in Healesville, Victoria. This dance features the Baṉumbirr Pole.

In the mid-2000s, Professor Ray Norris—a CSIRO astrophysicist and early proponent of Aboriginal astronomy—and his wife Priscilla visited Arnhem Land and met a prominent Elder to learn about the Morning Star ceremony. The Elders taught the couple a bit about the Baṉumbirr ceremony and its meaning. Out of curiosity, Professor Norris asked an Elder how the people know when Venus will rise as a Morning Star. The Elder replied, 'We count the days.'

The disappearance of Venus for a period of time before appearing as a Morning Star is tied to a complex cycle of the planet's daily movements. This affects when Venus is seen in the morning or evening. And just like the Sun and Moon, the position of Venus when it rises or sets changes each day, having a range on the horizon where it will set at its farthest point to the north and its farthest point to the south—just like the Sun's solstices or the Moon's standstills. Understanding the timing and position of Venus throughout this cycle requires careful long-term observation.

The Moon and planets have their own unique dances in the sky. Each

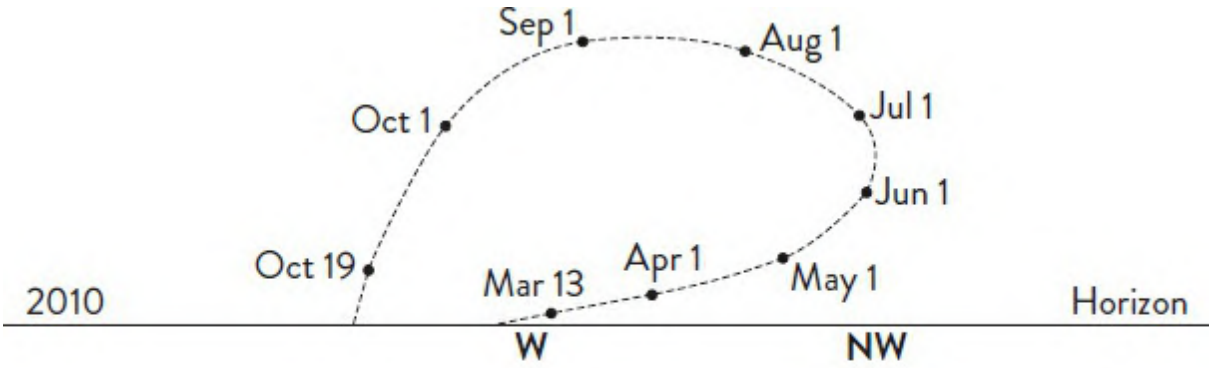
dance features several movements that eventually repeat. If you watch Venus carefully each day, you will notice a curious pattern emerge in its dance. After being visible as a Morning Star for about 263 days, Venus disappears below the horizon for 50 days. Venus then returns as a bright Evening Star for another 263 days, before it disappears below the horizon again. This time it is gone for only eight days before returning as a Morning Star. The total cycle lasts for about 584 days.

The Elders teach that if we watch Venus over the course of several years, we will notice that the planet's synodic cycle itself has its own longer-term cycle. Instead of counting the days, look at its position in the sky each morning or evening. You will notice that it traces out a distinct pattern during each synodic cycle of 263 days. Every eight years, the planet traces out five of these distinct patterns, the timing of each corresponding to the planet's synodic period. Five synodic cycles of Venus all have the same duration, but each one features different movements of the planet that repeat every eight years.

Western scientists describe the orbits of Venus and Earth as being in resonance, which is a state of balance between the two bodies as they move around the Sun. Venus is closer to the Sun, so it orbits faster. A year on Venus is only 225 Earth days. For every five times the Earth circles the Sun, Venus goes around it eight times. This is why, from our view here on Earth, we see Venus trace out five distinct patterns as a Morning or Evening Star that repeat every eight years.

Venus and the Aztecs

The disappearance of Venus for eight days before appearing in the early morning is reflected in Aztec traditions of Mesoamerica. The *Anales de Cuauhtitlán*, a volume from an Aztec codex, describes how two deities created the world. They are *Quetzalcoatl*, a feathered serpent and wise man, and *Tezcatlipoca*, the Aztec deity of night and sorcery. Their origin traces back to the Sun traditions described in Chapter 2: The Nearest Star.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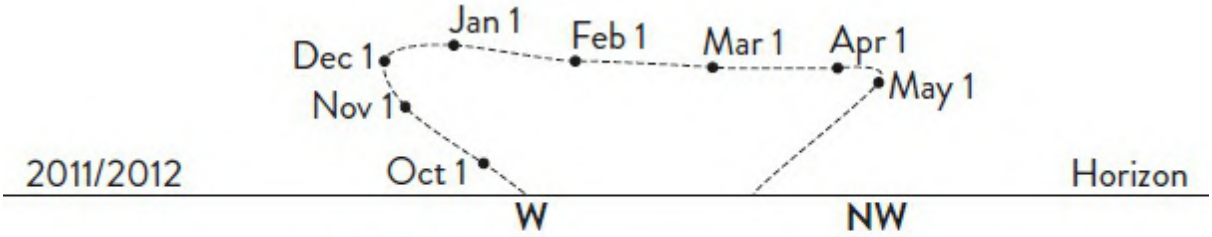
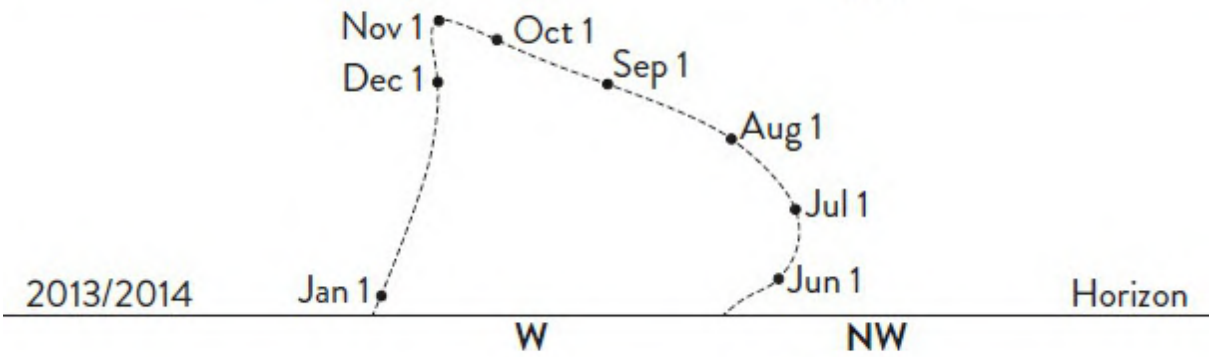
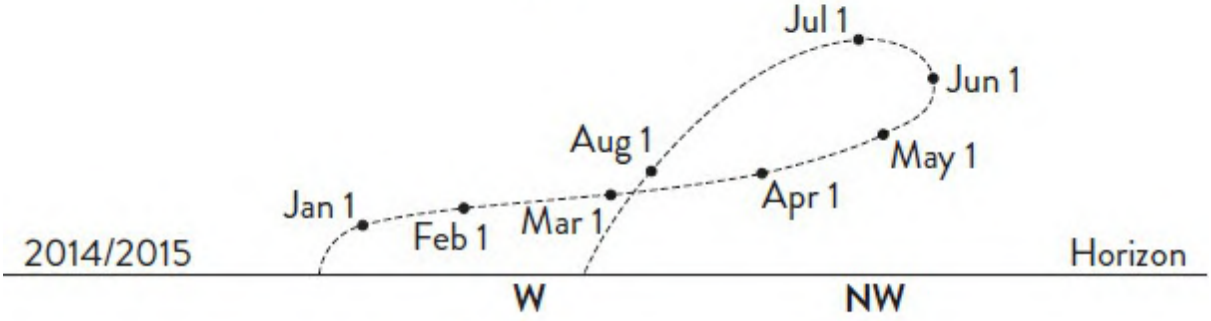
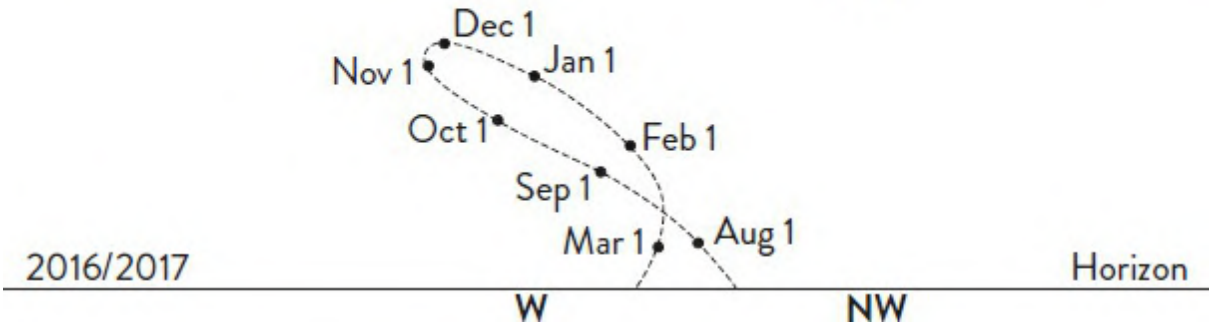
Aug 1
Oct 1
Jul 1
Jun 1
Oct 19
Apr 1
Mar 13
May 1
2010
Horizon
W
NW


Jan 1
Feb 1
Mar 1
Apr 1
Dec 1
May 1
Nov 1
Oct 1
2011/2012
Horizon
W
NW


Nov 1
Oct 1
Sep 1
Dec 1
Aug 1
Jul 1
Jan 1
Jun 1
2013/2014
Horizon
W
NW


Jul 1
Jun 1
Aug 1
May 1
Apr 1
Jan 1
Mar 1
Feb 1
2014/2015
Horizon
W
NW


Dec 1
Jan 1
Nov 1
Oct 1
Feb 1
Sep 1
Aug 1
Mar 1
2016/2017
Horizon
W
NW

The five apparitions of Venus as it appears in the sky half an hour past sunset for an observer at a latitude of 30 degrees south. Each apparition repeats every eight years.

Quetzalcoatl was driven out of the city of Tollan by Tezcatlipoca. He was forced to travel east to the sea, where he sacrificed himself by fire. Quetzalcoatl descended into the underworld for eight days. During that time, he managed to outsmart *Mictlantecuhtli*, the deity of the dead, rescuing humanity from the power of death. After the eight days, his heart ascended into the sky as the Morning Star (*Tlahuizcalpantecuhtli*). He set sail to the west with a promise to one day return, overthrow Tezcatlipoca and restore his kingdom.

Certain Aztec ceremonies were timed by the cycle of Venus. The Atamalcualiztli ceremony was held every eight years. The timing was intended to synchronise two significant celestial cycles: the eight-year cycle of Venus and the solar cycle, using the lunar cycle as a reference. This required a bit of mathematics. The Aztecs, as well as the earlier Mayan people, described the synodic cycle of Venus in eight-day increments. The cycles of Venus, the Sun and the Moon all come roughly into sync after a certain number of days. As with anything in nature, cycles never match up perfectly, but they are pretty close.

Eight Earth years consists of 2922 days. In *almost* the same amount of time, Venus will go through five synodic cycles. The actual number of days is a bit less: 2920. Ninety-nine lunar months of 29.5 days equals 2921 days. As you can see, the number of days in each period is off by only a couple of days every eight years. This is not an exercise in numerology. It shows us that First Peoples long ago worked out the complex cycles of the Sun, Moon and Venus, and figured out how these cycles synchronise.

Another aspect of the cycle of Venus described in traditional knowledges relates to its location throughout the series of successive synodic cycles. Just like the Sun and Moon, the planets travel within a few degrees of the ecliptic, which means their declination changes over time. This affects not only when they rise and set, but also where it happens. Just as the Sun has its solstices, the planets have their own version, called standstills—the northernmost and southernmost points at which they rise and set on the horizon.

If you look carefully, you will notice there are extreme points on the horizon where Venus will rise and set. If you want to know where and when

Venus will rise as a Morning Star, you need to know how this cycle works. Venus's standstills are spread about 50 degrees across the horizon. Whereas the Sun reaches a winter and summer solstice each year, Venus reaches an extreme standstill only once every eight years.

Western astronomers refer to these extremes as the maximum and minimum declination. And they, too, have importance in the traditional astronomies of First Peoples.

A seasonal indicator?

The Elders have long known that Venus, like the rest of the planets, is a wanderer. Venus will not be in the same part of the sky at the same time each year, making it a questionable tool for marking seasonal changes. It seemed unlikely that Venus could be used for this purpose. How can an object be a seasonal indicator when it wanders around the sky from year to year?

Before the Spanish colonised Mesoamerica, First Peoples of the region had long observed certain characteristics about Venus. They paid careful attention to the planet's standstills as it reached its northernmost and southernmost points on the horizon at dusk and dawn. When it was visible as an Evening Star, Venus always seemed to reach its southern standstill between October and December, *before* the winter solstice, and it's northern standstill in late April or early May. In Mesoamerica, the latter coincides with the start of the rainy season.

Similar patterns emerged when Venus was visible as a Morning Star: it always reached its southern standstill between late December and February, *after* the winter solstice. It ventured to its northern standstill between late June and August—again, after the summer solstice. Through these observations, First Peoples had worked out that the northerly standstill of Venus as an Evening Star coincides with the start of the rainy season, while its southerly standstill as a Morning Star coincides with the season's end.

So the wanderer *can* be used to predict seasonal rainfall—just not every year. The details can be a bit mind-bending, but it demonstrates that Venus obeys a complex set of rules and requires very careful, long-term observations to understand them. And that's exactly what First Peoples did.

CHAPTER 5

The Twinkling Stars

‘At night we look up at the Milky Way—when the stars twinkle on—they tell us about the weather. “This is the cold time, the cold weather is coming,” we say. When we look up at the stars and they are flickering, we say, “Oh, it is getting hot now, it is the hot time.”’

—Rusty Peters, Gija man from northern Western Australia

The twinkling stars have long inspired art and poetry. Hundreds of musicians feature the phenomenon in their song lyrics, from Ella Fitzgerald to Elton John, Carly Simon to Taylor Swift. In 1806, Ann and Jane Taylor penned the poem ‘The Star’ in the publication *Rhymes for the Nursery*. Thirty years later, the poem was set to the tune of eighteenth-century French folk song ‘*Ah! Nous dirai-je, maman*’ to become what we now know as ‘Twinkle, Twinkle, Little Star’.

The songs of First Peoples also describe the twinkling stars, but in ways that are less like nursery rhymes and more like a performative scientific text. In the eastern Torres Strait, Meriam man George Passi wrote a song called ‘*Uer Naskaisreda*’ (‘The Twinkling Stars’) in the mid-twentieth century. The song is poetic in its structure and delivery but serves a practical purpose. With lyrics in the Meriam Mir language, it describes the appearance of stars on a calm night, twinkling like embers in a fire. This signals a shift in trade winds from the southerlies to the north-westerlies (referring to the direction from which the wind blows).

First Peoples of the world are well acquainted with twinkling stars, which are often conceptualised in terms of action. Wardaman Elder Yidumduma Bill Harney describes the twinkling as stars ‘talking to each other’, while Northern Dené Elders of Canada say they are *wendaà hat’ı* (‘blinking their eyes’). From Moqoit traditions of Argentina to Inuit traditions of Arctic Canada, twinkling stars are described as ‘dancing’.

These songs and traditions are not simply descriptions of a mundane

phenomenon that has no practical application. Twinkling stars have a very important purpose, one I knew almost nothing about. In my experience, twinkling stars may have been pretty, but they were a headache when it came to astronomy.

For astrophysicists, they are a source of endless frustration. Their flickering nature disrupts our ability to collect precise and reliable telescopic data. Air turbulence makes stars twinkle, and humidity, dust, ice and temperature changes affect their visual properties, such as overall brightness, visual sharpness and colour. Astrophysicists refer to this as *seeing conditions*: how well we can 'see' the stars. The better the seeing conditions, the more stable, still and consistent the stars will appear, leading to better-quality data.

Six criteria are necessary for collecting accurate and precise telescopic data: clear, dark, cold, high, dry and calm skies. These criteria are important in the search for a site to build powerful optical telescopes. Mountaintops are the best, where the high elevation pushes the observatory up to a thinner and clearer layer of the atmosphere where the stars are as still as possible. Finding places that meet all these criteria is difficult.

The world's largest astronomical observatories are located on mountaintops in Hawaii, Arizona, Chile and the Canary Islands where the effects of stellar twinkling (called *scintillation* in Western science) are minimal. But many of these observatories were built on the traditional lands of First Peoples against their wishes, standing as an example of the push by Western science for innovation at the expense of the people and their land. As it turns out, the best place on Earth for telescopic observations is at Dome-C in Antarctica. This is where you will find that all six criteria are met.

Twinkling stars pose such a problem for astrophysicists that we go to great lengths to minimise or eliminate the negative effects of our atmosphere. This involves developing complex optical techniques and engineering telescope mirrors that can be physically warped in real time to cancel or reduce the effects of scintillation. We even go so far as to launch telescopes into orbit around the Earth at great cost—simply to bypass our atmosphere and all the trouble it causes. Consider the Hubble Space Telescope. Launched in 1990, it is a global symbol of ingenuity and precision engineering, at a running cost of 12 billion dollars. Most of the benefits—and the costs—are due to the telescope being high above our atmosphere.

To First Peoples of the world, the twinkling stars are not a hindrance or a problem to be overcome. They serve a critically important role in

understanding atmospheric conditions, with a variety of practical purposes.

Reading the stars

As Elders teach, there is a difference between ‘seeing’ the stars and ‘reading’ the stars. And the difference between the two is so wide it needs to be measured in light years.

It was 2014 when Professor Martin Nakata brought me to Mer to introduce me to local Elders and to discuss with them the community benefits and educational outcomes of the project. I returned the next year on my own and met Uncle Alo Tapim. Uncle Alo is a Dauareb man, meaning his people are from the island of Dauar. He is also one of the few remaining people whose first language is Meriam Mir. The Elder invited me to sit with him in his backyard under a large tree.

He introduced himself and after a brief chat explained that he was a gardener and that his star knowledge tended to relate to that aspect of his life. He explained that every gardener needs to be well informed about seasons, rainfall and weather patterns. Reading the stars provides insight into all of these and serves as a useful tool if you know how. ‘Reading the stars’, which we have touched on earlier, refers to recognising all of the subtle changes in the positions and properties of stars to tell you about your environment.

I wanted to better understand how Meriam gardeners predict rainfall. I told Uncle Alo that I once read that Polynesian navigators in the South Pacific observe the way stars twinkle to accomplish this and asked if Meriam people do the same. He smiled, nodded and explained how fishers and gardeners constantly read and interpret their surroundings, including the plants and the stars. Towards the end of the hot, dry Naiger season in October and November, the sky is very clear, and the stars shine brightly. When they begin to twinkle, people know to prepare for the coming wet Koki season that kicks off in December. He explained further:

> There are various signs that the seasons change. We see it in trees and gardens, but mainly in the stars. It becomes quite apparent towards the end of the year when you get the very clear skies and hot days because there are no clouds, and the same through the night. And the stars are very clear and colourful. When they twinkle, it heralds the wind picking up. Fishermen capitalise on that—giving them the idea that they will have a good day at sea. Or they can overnight at the reef and come back the next day by observing these stars.
>
> From spring to summer, we get that hot dry season where there are hardly any clouds in the sky. The word is doldrum, very fine—not a breath of air. It’s very still. During the night, when the dew sets in, you see the stars. They’re really shining and twinkling. It’s a good sign. It

> heralds the changes in the weather. Instead of the hot dry season, a wet season is coming. Locals always look forward to that. They observe the stars because the gardener is anxious. When is that rain going to come? They observe the stars, the plants and the path of the Sun.
>
> They are aware there is dew at night, even though the Sun is hot during the day. The dew rolls right into the dry ground, even though the ground may look dry and brittle on top. When a farmer digs down, it is cool and muddy inside, and this is a result of the dew. Dew keeps the soil soft inside. Maybe a baby cicada or something not fully developed is present. By observing that cicada, it is evident the Wet [season] is near. By observing the ground, the environment and the sky at night, the farmer is reassured that the wet season is coming.

Uncle Alo's description shows how observations of the stars are applied to navigation, gardening and fishing. This is not just one piece of information; it is a knowledge system practised in a holistic fashion. Everything is related, and a careful observer needs to consider the entirety of the local environment: not just the clouds, the stars, or the plants or animals, but everything.

While working on his master's degree at The University of Queensland, George Passi interviewed Elders across the Torres Strait, writing that:

> The [Islanders] know the right seasons to engage in such activities by observing the behaviour of the stars and constellations in the sky. In fact, it is the stars or constellations that are seen to govern the behaviour of plants and animals, which in turn influences the subsistence activities of the Islanders. The stars and constellations act as important guides to such activities.

Elders on the island of Erub, north-west of Mer, taught geographer Dr Karen McNamara that twinkling stars signal the beginning of the north-westerly trade winds. They explained to her in 2009 that:

> When they start to get the little rollers on the beach, it's flat calm, and they watch the stars, when the top stars, they twinkle more quickly, when the others twinkle more slowly it tells you something. Anyway, he [a traditional 'meteorologist'] read all the signs and said, 'It's gonna blow shortly', and then they start to get the rollers … Biru Biru [Rainbow Bird] is the one that flies out. They are signs of the nor-west [wind].

During another trip to Mer, I met with Meriam man John Barsa, who was regarded as an expert on traditional astronomy. His knowledge was deep, and he explained to me the way Islanders observe how fast the stars twinkle to measure wind intensity: the faster the stars twinkle, the harder the wind blows. If the stars twinkle quickly, but the wind at ground level drops, it is a good time to go fishing. He highlighted that stars *can* twinkle when there is no wind if it is really hot. But the twinkling looks a bit different—the stars on a hot night tend to shimmer more than twinkle. But observing just any star will not suffice. You have to know which ones to look at, and where. He says

you must always observe the bright ‘top-stars’, not the ones lower in the sky.

Storms and stars

The practice of reading the stars is widespread across the region. In the western Torres Strait, Mabuyag man Peter Eseli’s detailed journals contain a treasure trove of traditional knowledge in the Kala Lagau Ya language, including a wealth of astronomy. For 40 years his daughter, Mauare Eseli, was custodian of the manuscript before granting permission for it to be translated and published by linguists in 1998.

Mabuyag people link stellar scintillation to heavy winds, temperature changes and coming rains. The end of the dry season brings gusty winds and heavy squalls. The temperature drops to its lowest point, and rain clouds from the north-west bring the monsoon rains, a time when people experience strong, tearing north-west trade winds and heavy rainfall. During this time, Vega and the stars in Delphinus are twinkling heavily.

In Mabuyag traditions, the stars of the Western constellation Delphinus make up the trumpet-shell constellation *Buu*, and the star Vega is *Dhogay Ii*. The brief appearance of Dhogay Ii in late January in the dusk sky before setting below the horizon, and its reappearance in the sky at dawn, signals that the monsoon season is in full swing. The practice of observing the twinkling stars to predict the coming wet season is shared with Wardaman people near Katherine, Northern Territory. Uncle Yidumduma Bill Harney teaches that they know the monsoon season is approaching when *Ngilmungngilmung* (Canopus) twinkles heavily in the early morning sky in September.

Aboriginal and Torres Strait Islander peoples are not alone in associating scintillation with heavy winds, linking it to changes in seasons that are dominated by trade winds and rainfall. In the Arctic and subarctic regions of North America, we find remarkably similar explanations and uses for this phenomenon, even from cultures in radically different geographical environments. The languages of these regions use various phrases to describe the relationship between wind movement and stellar scintillation. I would learn this on a trip to the Hawaiian, Oceanic and Global Cultural Astronomy Conference in Hilo, Hawaii, in 2015.

It was there I met Chris Cannon, a University of Alaska doctoral candidate. He was working with Northern Dené communities across Alaska and

northern Canada, and they had taught him about their knowledge of the twinkling stars. Over a discussion, we realised there is remarkable similarity in traditional uses of stellar scintillation between the Northern Dené and Torres Strait Islanders, despite being on opposite sides of the world. The Torres Strait is a tropical, maritime environment in the southern hemisphere. Northern Dené Country is inland, subarctic/Arctic, and in the northern hemisphere. The similarities, as we realised, are not unexpected. The core cause of scintillation is the same, regardless of geography, but the ways in which it told you about the local environment were, of course, unique to that area.

First Peoples across the lands today known as Alaska and northern Canada teach the link between wind and scintillation. In the Koyukon language of western Alaska, *tloon' naa'ełts'eeyhleyaah* means 'the wind is swinging the stars', signifying the link between brightly twinkling stars and strong winds. The Gwich'in phrase *są' ch'adzaa* describes how winds make the stars dance. In the Ahtna language of southern Alaska, the phrase *son' nekenałts'iihwdelae* translates as 'the wind is sweeping the stars'.

An Ahtna Elder explained that:

> We know the wind blew, too. *Son'* [star] start moving all over. Big wind is headed down here pretty soon. We say Son' nekenałts'iihwdelae. Pretty soon going to be big wind down here. We know that, you know? Son' nekenałts'iihwdelae, just like he sweep over. Not hanging in one place, you know: everyplace.

That star is Sirius. If Sirius does not twinkle, then fine weather is coming. But if it flickers quickly, a storm is approaching.

Bengali farmers from Bangladesh observe the appearance of rapidly twinkling stars during *Joishtho*, the hottest month of the year in the Bengali calendar, which lasts from May to June. Rather than summer, it is spring that marks the hottest time of the year in Bangladesh. The temperatures cool slightly during the wet season in the summer months from June to September. The phenomenon is described as *Jodi Joishthote tara fute, tobe janbe borsha bote*, which translates to: 'If stars twinkle during Joishtho, it indicates heavy rainfall coming.'

The name Joishtho (Jyôishţhô) is derived from the Vedic constellation Jyestha (Jyeshţha), signified by the curve of stars in the tail and stinger of the Western constellation Scorpius. Jyestha rises in the south-eastern sky at dusk and sets in the south-west at dawn during the month of Joishtho, serving as an

annual seasonal marker.

The winds of change

Uncle Segar Passi's artworks feature a range of environmental scenes, mostly as seen from Mer and his traditional home, Dauar. Segar has a deep love for and knowledge of clouds and their relationship to the environment. He encodes his paintings with information about the land, animals, plants, clouds and stars.

Uncle Segar teaches that the stars are brighter and twinkle more towards the end of the year, signalling the arrival of the north-western *au uag* ('big wind') of the Koki. It is a challenge to represent the twinkling stars in a static painting. A more dynamic medium is necessary, leading to the song 'Uer Naskaisreda'. George Passi composed it when he was still living on Dauar with lyrics in the Meriam Mir language.

The song describes the effect of the trade winds on the appearance of the stars on a calm night. They twinkle because of the au uag, bringing rain clouds from the south-east to the north-west. Uncle Passi was a prolific songwriter, making music Uncle Alo describes as 'happy songs'. Meriam people still observe the twinkling stars today to forecast weather for fishing, carefully observing the way the stars scintillate to predict wind movement. If the stars are still, there is no wind. This could make getting home a challenge. If they see the stars twinkling, they know they will have the wind necessary to push the sails back home.

Uncle Bob and Uncle Meddy Kaigey explained something that I found confusing. When Uncle Alo Tapim translated the lyrics of 'Uer Naskaisreda', it was clear that a few words were used to describe stellar scintillation and they seemed to have a similar root in the language. In Meriam Mir, *epreki* refers to a popping sound, like the crackling of twigs in a fire or the sound of a gunshot. However, the word *baprikeda* refers to 'sparks or sparkling', and this refers to stars twinkling quickly. The term *naskaisreda* refers to both a change in colour as well as the change in brightness you might see when kicking embers of a fire into the air. It represents the slower twinkling of stars.

Similar practices are maintained by Polynesian navigators of the Pacific. Māori seafarers of the South Island of Aotearoa/New Zealand teach that the bright twinkling of *Atutahi* (Canopus) is caused by 'hard-blowing' winds in

October, which signal the approaching summer. A traditional story from Tonga, recorded in the eighteenth century and translated into English, recounts a perilous voyage in which the sailor Longa-Poa observes twinkling stars to forecast trade winds:

> Let not your hearts be sore, my men. Good is our sailing! A good wind! A smooth sea! It will be a fine night, for there are many stars. See also how they twinkle! Therefore, will this north-east wind continue to blow.

Star colours

According to John Barsa, it is important to look at other properties of stars as they twinkle, including their colour. Blue and white twinkling stars that rapidly change colour to red and orange indicate both strong winds and changes in temperature. Blue and white twinkling stars that do not change colour indicate the fine weather and constant temperatures of the hot Naiger season. If the blue and white stars are twinkling rapidly, they forecast approaching storms, which increase with regularity and severity near the start of the wet Koki season in late December, lasting until April. At the end of the Naiger, the trade winds begin shifting from the south-east to the north-west.

One can also predict changes in temperature by observing the intensity of stellar scintillation. In Gwich'in traditions of Fort Yukon, Alaska, the stars appear more 'magnified' in September before the arrival of the intense cold. Elders of this region say that when the weather is colder, the twinkling of the stars is less prominent. In warmer weather, the scintillation is more pronounced. In this region, observations of twinkling stars are often described in the context of cross-country travel and hunting activities that occur between September and April.

One can observe the colours of stars in relation to the way they twinkle to make predictions about rain, storms, temperature and wind. In the Torres Strait, the end of the year brings seasonal changes as shifting trade winds transition the Naiger to the wet Koki season, causing the stars to twinkle. This is explained in the song 'Uer Naskaisreda'. If the stars twinkle quickly *and* appear very blue in colour, rain is imminent. Humidity can change the extinction coefficient of a star's light. Water absorbs red and green light but is very poor at absorbing blue and violet light. Under the right conditions, this can alter a star's apparent colour.

Changes in star colours, combined with the winds that make the stars

twinkle, signify humidity and wind: a recipe for rain. But this only works for stars brighter than about magnitude 3.1. For comparison, Sirius, the brightest star, is magnitude −1.46, as the lower the number, the brighter the object. (See the Glossary to better understand the magnitude scale.) Stars fainter than this threshold are visible only to the light- and dark-sensing photoreceptor cells in our eyes: rods. Cones, the colour-detecting photoreceptor cells, function well for stars brighter than magnitude 3.1. This is one of the reasons Elders say to look to the brighter stars, not the fainter ones. You will not notice colour changes for fainter stars, and similarly their twinkling will be more difficult to notice than the twinkling of brighter stars.

Inuit Elders in Iglulik, Canada, refer to Sirius as *Singuuriq*, meaning 'the flickering one'. The star never reaches more than about 4 degrees above the horizon as seen from that latitude, but it is so bright that it is easily visible. Despite this, Singuuriq's light is susceptible to drastic changes in colour. Iglulik Elder Hubert Amarualik teaches that Singuuriq is used to predict the weather and the severity of temperatures. When the weather is extremely cold, the star turns reddish. If the star does not twinkle, milder weather will come. When the wind is going to blow, the star behaves like a flame exposed to a draught.

The animals

Observing the changing colours of stars has other practical purposes. Late Inuit man Peter Kamingoak, from Kugluktuk in Canada's Northwest Territories, said that Sirius is known as the 'fox star', with the traditional name *Kajuqtuq Tiriganniaglu.* The two-part name refers to *Kajuqtuq,* the red fox (*Vulpes vulpes*) and *Tiriganniaglu,* the white Arctic fox (*Vulpes lagopus*).

The animals begin their search for a home in March as the duration of sunlight slowly increases with each passing day. This is when Kajuqtuq Tiriganniaglu reaches its highest point above the horizon after dusk. Despite this, it's not very high in the sky at all. It only rises to around 5 degrees—about the width of your first three fingers at arm's length. We will discuss this in Chapter 9: The Navigational Stars.

Because the star is so low in the sky, its intrinsically white light passes through a thick layer of the Earth's atmosphere before it reaches the observer's eyes. Pockets of moving air, each having slightly different densities and temperatures, alter the refraction index of the incoming

starlight, causing it to change colour as it twinkles. This makes the normally white star appear to flicker between white and red.

Dens are a limited commodity in the Arctic and competition among foxes is fierce. This is why the star Kajuqtuq Tiriganniaglu has a two-part name—it is seen as a red fox and a white fox fighting to gain access to a single den. By April, the breeding season has begun, and the successful foxes have settled into their new homes. Kajuqtuq Tiriganniaglu then sets with the Sun and is no longer visible.

There are many other examples of twinkling stars being connected to animal behaviour. On a December afternoon at Tagai State College on Mer, Meriam man William Bero was teaching me how the twinkling stars predict coming storms. He took me on a walk around the grounds of the college, explaining that the intensity and speed of the twinkling stars tell you how severe the storm will be, and that this is connected to the behaviour of a colourful butterfly (of the genus *Ornithoptera*). He led me to a bushy area in search of the insect.

He explained that the male of the species is bright in colour, featuring green, red and gold markings, which he likened to reggae flags. They are particularly fond of citrus trees and normally hide away—until a storm approaches and the males fly about while the females stay hidden in the bush. When Meriam people see the butterflies fluttering out in abundance, they know to begin preparing for a coming storm. This tends to occur towards the end of the year as the monsoon season approaches, the winds shift and the stars are flashing in the night sky. A similar connection was made by Burarra Aboriginal communities in Arnhem Land, who realised that when butterflies become active the monsoon rains will soon arrive.

Uncle William's insight revealed another layer of interconnectedness, showing the link between the twinkling of stars, the coming monsoon rains and the behaviour of insects. I was keen to learn more, as I knew I was only scratching the surface of the depth of this knowledge. I wanted to meet up with John Barsa again, whose star knowledge was deep. Uncle John had shared a wealth of information during our earlier interview, but as it had taken place during the day and he only knew the Meriam names of the stars and constellations he described, we agreed to catch up one night before I left so he could point out the stars and show me how to read them.

Unfortunately, issues of daily life kept getting in the way and our nocturnal meeting never eventuated. When I came back to the island in 2016 and 2017,

Uncle John was in Cairns to see family and visit the doctor. We kept missing each other. In January 2018, Uncle Alo phoned me with terrible news—John had passed away. He was only in his mid-fifties. This is a tragic but not uncommon reality for many Aboriginal and Torres Strait Islander people, where life expectancies are often ten to twenty years below that of the non-Indigenous population.

There is an old saying that when an Elder dies, a library dies with them. This was certainly the case with Uncle John. He was keen for his knowledge to be shared, and his family remains supportive of promoting his legacy.

Icy and muddled stars

As I learned about the different ways twinkling stars are used to predict weather, I remembered something I saw during a conference excursion in South Africa in 2014. During the tenth meeting of the International Society for Archaeoastronomy and Astronomy in Culture (ISAAC), Dr Jarita Holbrook, an astrophysicist and African cultural astronomy expert, led a field trip to the Sevilla Rock Art Trail near the town of Clanwilliam on the Western Cape. We stopped for lunch at a winery. On one of the walls was a glass plate featuring San artwork that discussed the star Sirius. It said that San people sing to the star Sirius during winter in the hope the Sun will become warm again. Their song influences the turning of the seasons, which is reflected in their traditions and ceremonies.

I was directed to ethnographic records from 1911 that detail how San (*/Xam-ka-!k'e*) pay close attention to when the stars *!keisse* (Canopus) and *!kuttau* (Sirius) rise just before dawn and are twinkling rapidly. The stars' appearance signals the time for an annual ceremony. San traditions regard !keisse as a child, and !kuttau as an ancestral grandmother carrying rice. The people carefully watch for !kuttau's first appearance in the morning, just before dawn.

A witness to the ceremony said that when the star appears, the people call out to one another: 'Grandmother shall make a little warmth for us; for she coldly comes out. The Sun shall warm grandmother's eye for us.'

!keisse, the child, is responsible for acquiring a stick that is burning at one end. This star rises first. Later, when !kuttau is seen, the people sing to the star and point the burning stick at it to encourage warmth and light. The people then look for when !kuttau twinkles like !keisse. In southern Africa,

Canopus rises at dawn in early May. It is not until mid-June that Sirius appears at dawn. When it does, it twinkles like Canopus, marking the start of winter and signalling a peak in westerly trade winds, which drop in summer.

San women rejoice when seeing !kuttau flickering in the dawn sky, shouting, 'Sirius! Sirius! Winks like Canopus!'

You might recognise that the same stars keep coming up in this discussion, the most prominent being Sirius and Canopus. These are the two brightest stars in the sky and the stars in which it is easiest to detect changes in brightness and colour. They are also high in the sky at southern mid-latitudes. Elders from Alaska to Australia teach us to observe the 'top' (high-altitude) stars.

Stars are more likely to twinkle and change colour if they are fainter or at a low altitude. That makes reading them a challenge, as they are already susceptible to these effects of stimulation. But the stars that are both bright and at a high altitude are much better for gauging atmospheric conditions. You cannot simply pick any random star. You have to know how the atmospheric conditions impact and influence each type of star and where they are in the sky. This is no easy feat, but First Peoples worked it out long ago.

Sailor and scholar David Lewis spent much of his life learning about navigation from Melanesian, Polynesian and Micronesian sailors across the Pacific. In 1969, a canoe captain named Itilon from the Ninigo Islands of Papua New Guinea taught Lewis that local navigators observe a trio of bright stars called *Maan* to determine wind direction and weather. Maan consists of Sirius, Canopus and Procyon—the first, second and eighth brightest stars in the night sky, respectively.

If twinkling and colour changes can be read to interpret atmospheric conditions, what other properties might be noticed? Samoan navigators watch the red star *Le Tāelo* (meaning 'stinging striker') to forecast approaching cyclones. They say it twinkles constantly and has a jagged appearance at the edges when a storm is coming. The same principle is noted by Alaskan Yup'ik Elder Bob Aloysius, who refers to blurred or fuzzy stars as '*tloon' tl'ołeł yee daadletl'ee'*, meaning 'the stars are sitting in their cradles'. This refers to a special combination of wind and ice in the atmosphere that produces tiny haloes around the stars.

Humidity can also blur the appearance of stars, indicating conditions ideal for rain. This link is known to farmers, who use the folk saying, 'When stars become a muddle, Earth becomes a puddle.' Bob Aloysius says that

sometimes twinkling stars will appear to have small tails. These tails show the direction of blowing wind: if the tails point south, the wind is coming from the north. In a similar fashion, Polynesian traditions from Tahiti note that the appearance of the Milky Way can ‘bend’ due to high winds.

The twinkling … planets?

Students learn in primary school that ‘planets do not twinkle’. This is one of the common methods astronomy educators teach the public to distinguish stars from planets. In terms of physics, the light from planets *does* twinkle, but it is not normally discernible to our eyes. This idea is well known to First Peoples, who long ago observed that the wandering stars do not usually twinkle like the fixed stars.

In northern Alaska, the Inuit name for the planet Mars is *Kayaktuq*, which is also the name of the red fox. And, just like the star Sirius, Mars is sometimes seen as a red fox and a white Arctic fox battling for the same den. This tends to occur when Mars is low on the horizon, and for the same reason as Kajuqtuq Tiriganniaglu.

In northern New South Wales, Euahlayi traditions say that when Venus is low on the horizon, it can twinkle and change colour. Elders say this is an old man who told a crude joke and is laughing animatedly: ‘He’s a rude old man, that Laughing Star.’

I think we’ve all known someone like this.

CHAPTER 6

The Seasonal Stars

‘The stars and constellations govern the behaviour of plants and animals, which in turn influences our subsistence activities. They act as important guides.’

—George Passi, Meriam scholar and Elder

Growing up in Missouri and living in Melbourne quashed any hope I had of understanding weather prediction. Despite being on opposite sides of the planet, both places are infamous for wildly changing weather, with locals simultaneously joking and commiserating about experiencing four seasons in a day. Sunny and warm one day, dark and snowy the next is a common springtime occurrence in the ‘Show Me’ State (I have experienced this change in the same day), and Melbourne can turn from fiery inferno to refrigerator in what feels like minutes when a southerly breeze blows in.

Missouri and Melbourne are crossed by two different climate regions. Missouri is in the middle of the North American continent with the hot, humid Gulf of Mexico 1000 kilometres to the south and the freezing Hudson Bay 2000 kilometres to the north, in a region channelled between the Appalachian and Rocky mountains. The dynamic interplay of converging hot and cold air is the main reason Missouri is part of ‘Tornado Alley’. Those who think pigs can’t fly have never experienced a twister in America’s rural Midwest.

Similarly, Melbourne is sandwiched between the prevailing winds of the hot, arid continental interior of Australia to the north and the chilly winds of the Bass Strait to the south. The work of a meteorologist in places like these seems more like that of a mystic with a crystal ball than any type of science. Aaron Bon, a ranger from the central Torres Strait, told me a Yumplatok (Torres Strait Creole) phrase used when someone does something wrong: *Theh now wandeh lisen po weda* (‘That’s what you get for listening to the weatherman’).

This summed up my thoughts on weather forecasting. In some places I assumed the job of a meteorologist would be a lot easier. I once joked that in Darwin it must be pretty easy, with forecasts coming down to two options: hot and wet, or hot and dry. How wrong I was. The local Larrakia calendar includes seven main seasons, which are based on rainfall, plants, animals, wind and dew.

Unlike the four Western seasons, which are based on the solstices and equinoxes, the seasons of First Peoples are based on local applications and observations linked to rainfall, wind, animal and plant behaviour, and the positions of stars. These seasons may number more than twelve and may have subsidiary seasons. They are also not evenly spaced in duration. Instead, they are as long or short as the local environment dictates.

Just as meteorologists possess a range of algorithms and models to forecast weather, First Peoples utilise a toolkit for this purpose, including many astronomical tools. These tools are developed through observation, correlation, application and deduction, and include the appearance or disappearance of bright stars at dusk and dawn, the visibility of star clusters and the orientations of constellations throughout the year. Observing the stars to track the seasons is one of the most common and widely known uses of the night sky, but how this is accomplished varies from place to place. As Professor Martin Nakata points out, Indigenous Knowledge is developed and applied locally (in situ).

Selecting stars to mark seasonal change is not easy. You cannot just pick any random star. Timing is critical, and this is largely dependent on the stars' *declination* and *right ascension*: their coordinates in the sky. A star's declination denotes its pathway across the sky and how long it will be visible; its right ascension denotes when it will be visible (we will discuss these in detail in Chapter 9: The Navigational Stars).

In addition to timing, the rising and setting of stars must link together as part of a larger map and memory space. A seasonal star's relative position to other celestial objects is important, as are the star's colour and brightness. The brightness often reflects its importance and colour reflects the appearance of an animal or plant. They inform observers about things happening on the land, but they also serve as a memory aid. So, selecting the right star to link to the right thing on land at the right time of year and connecting them through a useful narrative that can be passed through memory over several generations is a challenging task!

It would be impossible to explain the full range of Indigenous seasonal calendars across Australia or the world; there are simply too many, and each one is detailed enough to fill a multi-volume encyclopaedia. Rather, we will examine some of the core relationships between the observations and interpretations of stars and how this relates to seasonal change and rainfall as well as food economics. To accomplish this, we will look at examples from cultures in Australia, Africa, the Pacific and South America.

The dark constellations

When we think of constellations, we tend to imagine a group of bright stars that are connected by imaginary lines to trace out a familiar pattern. Some are easily recognisable, like Orion, Scorpius or the Southern Cross. Others are a bit more of a challenge to make out. Of course, each culture has its own constellations, and many of them do not follow the same 'rules' set out by Western science. Indigenous constellations can overlap with one another, and they can have different meanings and names throughout the year, depending on their movements and orientations.

They do not all have to be made up of bright stars. They can also be traced out by the dark spaces *between* the stars. These 'dark constellations' are formed by the contrast of light and dark spaces in the Milky Way—areas of our galaxy the Mayan people refer to as *Saki bé* ('white road') and *Xibalbá be* ('path to the Underworld'), respectively. Regarded by astrophysicists as areas of cool interstellar gas and dust, First Peoples describe these dark spaces as animals, caves, waterways or serpents. The misty white glow of the Milky Way resembles smoke, sparks from a campfire, the banks of a river, or, as the name suggests, flowing milk.

Some of these spaces form distinct shapes, such as a sinuous dark nebula stretching across the Milky Way from the Southern Cross to Vela. This nebula is described by Wiradjuri people of central New South Wales as *Wāwi*, a serpent-like creature possessing magical powers that burrows deep into the bank of the sky river where he makes his den. The same sinuous black streak is described in Quechua traditions of South America as a serpent (*Mach'acua*) in *Mayu*, the sky river of the Milky Way.

Arguably the most famous example of a dark constellation in Australia is that of the emu, the celestial counterpart to the country's large flightless bird. The emu constellation comprises the dark spaces in the Milky Way between

the Southern Cross and Sagittarius. The head of the emu is the Coalsack Nebula, bordering the Southern Cross. The nebula's resemblance to the side profile of an emu's head is remarkable! You can see the head and beak, and a conspicuous star in the exact spot where an emu's eye would be.

The neck stretches down through Centaurus into Scorpius. The body is traced out by what astrophysicists call the 'galactic bulge'—the centre of the Milky Way galaxy as seen from Earth, at the intersection of the Western constellations Scorpius, Serpens and Sagittarius. The legs stretch back into Sagittarius, with a few of the dark spots seen as the emu's eggs. The name of the celestial emu is as diverse as the 250-plus Aboriginal languages of Australia, as are the stories describing how it ascended into the sky. But at the core, the traditions share a common theme: the position of the emu at dusk and dawn informs the people about the emu's behaviours, the changing seasons and the time to hold specific ceremonies. The position is also central to an important food source: the large and highly nutritious emu egg.

Uncle Ghillar Michael Anderson teaches traditional Euahlayi knowledge of *Gawarrgay*, the celestial emu, showing how the bird's position in the sky at dusk signals a wide range of practices and events. When the Sun sets and the stars emerge, the silhouette of the emu in the sky takes form. It starts to rise in March, becoming more prominent in the evening sky through April and May. At this time, it is perceived as a female emu running. When she is courting a male, she runs in a circle around him to gain his attention.

April to June is the breeding season, where the males begin building nests and the females lay eggs. Females can lay several clutches of eggs, with each one consisting of five to fifteen eggs. Each egg weighs about half a kilogram. The energy required for females to produce these eggs is considerable. She does not then have the energy to build the nest, incubate the eggs, protect them from predators and rear the young. These are the male's responsibilities.

In the period from April to June Aboriginal people collect the eggs for food. Wiradjuri astrophysicist Kirsten Banks presented a talk at TEDx Youth@Sydney in 2019. She described how Aboriginal people form teams to collect the eggs. One uses an 'emu caller', a device that looks like a short didgeridoo. When they strike the end with the palm of their hand, it produces the deep, guttural thumping sound of an emu. The territorial male, thinking it is a rival, leaves the nest to protect it. This is when the other team swoops in, grabbing a few eggs and leaving before the male emu returns.

The perception and meaning of the celestial emu changes from season to

season. From June to August, Gawarrgay is high in the sky at dusk, lying roughly horizontal from the east to the southwest. No longer seen as a female running, it is now a male sitting on the nest. He closely guards the eggs, abstaining from food and water, and doesn't get up or leave the nest except to turn the eggs or protect them from a predator. The incubation period for emu eggs is about eight weeks.

From August to September, the chicks begin hatching. Now the celestial emu lies perpendicular to the south-eastern horizon at dusk and is seen as a male emu getting up from the nest to begin rearing the young. In some parts of south-east Australia, this was connected to an initiation ceremony. The ceremonial grounds generally consist of two circles of rock or raised earth about 200 metres apart, connected by a pathway. The larger circle is the 'public' area, and the smaller one is where the secret business occurred between the initiates and the senior Elders.

The ceremonial sites are called Bora and are seen as a reflection of the cosmic ceremonial ground. This comprises the same part of the Milky Way as the celestial emu. Bora ceremonies took place at night, usually around August and September, with the ceremonial site aligned to the Milky Way in the south-west. The male emus rearing the chicks is symbolically related to the Elders guiding the boys to manhood. As it is above, so it is below.

In October and November, Gawarrgay continues rotating in the sky, until it lies belly-up along the horizon. Uncle Ghillar teaches that the emu is no longer seen lying on its back; instead, the emu's body now resembles the rump of the bird sitting in a waterhole. At this time, the weather heats up and the birds seek respite in the puddles that form as seasonal rainfall increases. In the sky, Gawarrgay sits in the celestial waterhole, displacing the water like a cosmic Archimedes in his bathtub. This water falls as the seasonal rains of spring.

October and November see a dramatic rise in seasonal rainfall in the region. Rain is lowest in August and September, then it spikes in October and peaks in November, more than tripling. The celestial emu drops below the horizon over the summer months before returning in autumn. Uncle Ghillar teaches how the celestial emu informs seasonal change, the behaviour of the bird, food economics and ceremony.

In north-western Victoria, Wergaia Elders teach about *Tchingal*, the celestial emu. But this was no typical emu—it was a giant killer emu that would eat people. Two brothers were sent to kill Tchingal and managed to do

so by spearing it in the neck. The spear can be seen in the sky as the two Pointer stars.

Traditions about a large flightless bird traced out by the dark spaces in the Milky Way are not restricted to Australia. First Peoples of South America have traditions about a similar bird called a rhea, and its meaning in the sky throughout the year is almost identical to that of the emu. Rheas, emus and ostriches are all ratites: large, flightless, long-legged birds. The celestial rhea is featured in the knowledge systems of Tupi people in the Brazilian Amazon and of Moqoit people in Argentina.

In Moqoit traditions, all animals and edible plants have a protector or 'master'. They are identified as the father (*leta'a*) or mother (*late'e*) of the species. This protector regulates human access to the plants and animals as resources, ensuring a sustainable balance. Mañic is the master of the rheas that will kill and eat humans. It seeks shelter in burrows and under the roots of the ombú tree (*Phytolacca dioica*, represented by the Milky Way). Lapilalaxachi, a powerful ancestor represented by the Pleiades, decided to face the Mañic. He pursued Mañic across the country. When cornered, the rhea climbed up the trunk of the ombú tree into the sky. You can see the *la 'al* (shadow-soul) of Mañic in the dark spaces of the Milky Way. The Pointer stars are the dogs of Lapilalaxachi that bite the rhea's neck.

Stellar correlation

In the islands of the Torres Strait, the story of Tagai informs the people about changing seasons, traditional Law and the behaviour of animals—all through the movements of the stars. In Meriam traditions of the eastern Torres Strait, Tagai was considered a highly respected leader and a great warrior, hunter and fisher. He commanded a canoe with Kareg, who is described as his first mate and *kaimeg* (friend), and a crew of twelve men. Kareg sits at the stern of the canoe and the crew are arranged in two rows of six. Tagai commands from the bow as a *Zogo Le*, a spiritual man who carefully observes the seas and weather, navigates by the stars and interacts with the spirit world.

Long ago, Tagai and the crew departed on a spear-fishing expedition. The crew grew hot and thirsty and, despite warnings from Kareg, the men drank all the water rations, including Tagai's. When Tagai saw the empty drinking vessels, Kareg told him what happened. Tagai flew into a fit of rage and cast the crew into the sea.

Since the men themselves were spirit beings, they could not technically be killed. So Tagai bound one group of six men and cast them into the sky as *Usiam*, the stars of the Pleiades. He cast the other six men into the sky to become *Seg*, the belt and scabbard stars of Orion. Since Kareg was his trusted friend and did not consume the rations, he was spared.

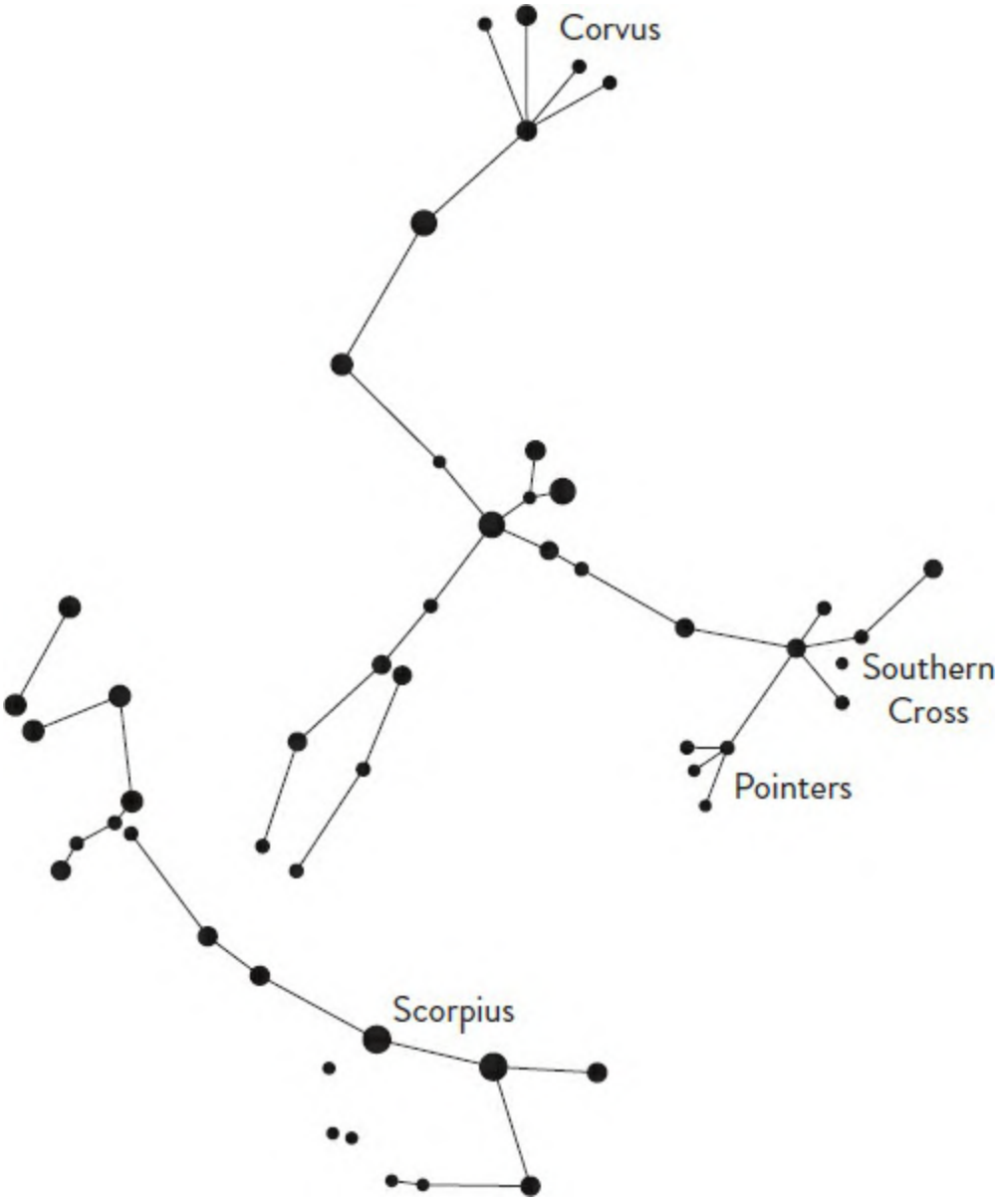
Tagai and Kareg then ascended into the stars. The commander became a large constellation, stretching across the night sky. He stands with his arms outstretched, holding a spear and standing on the canoe. Tagai's right hand is represented by the five bright stars of the Western constellation Corvus, and his left hand comprises the five stars of the Southern Cross. Tagai's eyes, nose, mouth, shoulders, elbows, torso, genitals and legs are represented by stars in the Western constellations of Lupus, Centaurus and Hydra. He is standing in the canoe, which is traced out by the bright stars of Scorpius. Kareg sits at the stern as the bright red star Antares.

In his anger, Tagai cast Usiam and Seg into the opposite side of the sky to keep them far away from him. This bears a striking similarity to the story of Orion and Scorpius in Ancient Greek mythology. Orion claimed he could kill any animal on earth, which angered Gaia, the Earth Goddess. She sent a scorpion to kill him and after an impressive battle the scorpion emerged victorious. Zeus placed the scorpion in the sky as the constellation Scorpius while Orion was placed on the opposite side of the heavens so they would never fight again.

When the star groups of Tagai and Kareg, Usiam and Seg rise and set throughout the year, they signal changes in the seasons. The crew causes the rain, wind, weather and certain tides (the latter of which the Islanders also link to Moon phases). When they dive into the sea at dawn in November and December, they splash water into the sky that then falls as the monsoon rains. At this time, Tagai directs the gardening practices of the people, who do their work in the early morning before sunrise and late evening after sunset to avoid the intense heat of the Sun. Tagai rises at dusk in March and sets in October. Islanders developed a complex seasonal calendar around these stellar movements, which guide practices ranging from hunting and gardening to ceremony and navigation for long-distance sea voyaging.

In Meriam traditions, the rising of Tagai's hands in late March foretells the wet, north-westerly winds of the Koki. Soon afterwards, the dry south-easterly winds of the Sager start to blow, but the monsoon rains are not quite finished for the year. April sees roughly equal periods of Koki and Sager

weather. By May, the right hand of Tagai (Corvus) is high in the sky. This is when turtles come onto the sandy beaches to lay eggs.



The Tagai constellation

By late May, Kareg (Antares) rises, signalling the time that *moramor* (a small red bug with black markings, of the Hemiptera order) begins to attack yam leaves. Kareg is said to send these bugs in May but drives them away weeks later when he appears higher in the sky after sunset. A few months

later, around mid-September, Tagai's hands set at dusk, indicating the time for gardeners to plant bananas and yams for the year. Similarly, the Kauareg people of the south-west Torres Strait harvest two species of yam, *kuthai* and *sawur*, in the months during the Sager.

People on Mer look for when Tagai sets in October and appears to hug Au Passer (the big hill) on Dauar. They know to begin planting gardens and preparing for the Koki. By mid-November, Tagai and Kareg have both set below the horizon at dusk. By late November, Usiam dives into the sea at dawn, followed a month later by the stars of Seg.

Meriam traditions also describe a cosmic shark, named *Beizam*, which is formed by the stars of the Big Dipper, part of the Western constellation Ursa Major. When Beizam dives into the sea later in the year, water rushes through its gills and falls as the *Kipagogob*, the first rains of the Koki. We will learn more about Beizam in Chapter 9: The Navigational Stars.

Another way to link knowledge to memory is through colour association. On the eastern end of Mer lies Las Reef, on the traditional lands of the Samsep community. Here lies a large black rectangular stone that symbolises Tagai's canoe, and a red stone that represents Kareg, the bright red star Antares. The red moramor bug is associated with Kareg for the same reason.

Just as Elders teach that everything on the land is reflected in the sky, Mabuyag Islanders in the western Torres Strait regard their star maps as virtual reality reflected in a mirror. They show that events in the sky have counterparts to events on Earth and that by reading the stars, you can read the land. They also teach you how to read the sky to forecast the weather.

Forecasting rainfall

Usiam serves as one of several seasonal markers in the Torres Strait. The star cluster sets into the sea, splashing water into the sky that falls as the Koki rains. Across Australia, the appearance of the Pleiades is linked to seasonal rainfall. A personal experience highlighted how this works in ways I had not considered, leading me down a pathway that would forever change how I conceptualised observations of the stars.

In 2017, I worked as a consultant for the Royal Australian Mint to develop a series of three commemorative coins celebrating Aboriginal and Torres Strait Islander astronomy. I suggested that one of the designs should come from the 2009 exhibition *Ilgarijiri* (meaning 'Things Belonging to the Sky' in

the Wajarri language of Western Australia). This exhibition was a collaborative effort between astrophysicists who are developing the Square Kilometre Array (SKA) radio observatory and the Wajarri-speaking Yamaji Traditional Owners of the Murchison region of Western Australia where the telescopes are being built, with a planned completion date of 2030.

Discussions with Yamaji Art, the local Aboriginal-owned art centre, led to the selection of an artwork by Christine Jugarnu Collard for the second coin. This artwork featured the story of *Nyarluwarri*, the Seven Sisters (Pleiades). In Yamaji traditions, the stars represent a group of young sisters being pursued by a man in the constellation Orion as they move from east to west each night. His sights are set on the youngest sister, the faintest of the seven in the cluster, who is protected by her older siblings. When this cluster of stars appears low on the horizon at dusk, it signals the start of the emu-breeding season. This is when the people can begin harvesting the eggs.

As the celestial emu rises in the south-east, the Pleiades set in the north-west, appearing low on the horizon after dusk in early April. By late April, the stars have set with the Sun. Charmaine Green, a Yamaji woman and the Director of Yamaji Art, explained that one can predict seasonal rainfall by observing how bright the cluster is at certain times of the year. If fewer stars are visible than normal, and if they seem ‘muddier’ in appearance, rainfall is likely. As this area is prone to drought, it is critically important for the Yamaji to read natural signs to estimate the amount and duration of rainfall they are likely to receive.

How does this work? The Pleiades is one of the most striking and conspicuous star clusters in the sky. Due to its position near the ecliptic, it is visible from pretty much anywhere in the world and is featured in the traditions of nearly every culture. The cluster contains an astonishing 3000 stars, but only a handful of them are visible to the unaided eye. Most people see only six or seven, but keen observers can make out twelve or more under ideal conditions.

Atmospheric and environmental factors influence how clear the cluster appears and how many individual stars you can see. If ice crystals are present, they diffract incoming starlight. Fewer stars of the Pleiades will be visible, and they will not be as bright. When conditions are drier, more stars are visible, and the cluster appears brighter. On dark, dry, clear nights, the Pleiades can seem 25 per cent ‘bigger’ as the fainter stars come into view. These additional stars increase the total area of the visible cluster.

Knowing how to interpret the appearance of the Pleiades requires significant skill. The Yamaji are certainly skilled in this regard, and they are not the only ones. Indigenous communities in the Andes Mountains of South America apply this knowledge in a similar, but distinctly unique, way. And this was something that Western science came to learn more about only in recent years. The climate of the Andes is dry and harsh. At elevations greater than 3600 metres, you will find few trees and flora is limited to low, scrubby vegetation. Despite the rugged desert conditions, patches of crops—mainly potatoes and yams—cover steep hillsides and provide the majority of food for Aymaran and Quechuan communities. In this environment, a successful harvest is a matter of life and death. As with the Yamaji of Western Australia, it is critically important for farmers in this region to estimate the rainfall. Predicting this accurately means yielding a larger potato harvest the following year. Failing to interpret the signs properly could result in mass starvation.

But rainfall in this environment is not restricted to annual cycles; it is also dependent on the longer-term climate cycle of El Niño. Rainfall in the Andes of Peru and Bolivia is distributed unevenly throughout the year. It is highest from December to February, and lowest from May to August, with the least rainfall and fewest rainy days occurring in June and July. Aymaran and Quechuan farmers use an ingenious astronomical technique to forecast seasonal rainfall during El Niño. An hour or so before sunrise around 15 June, farmers climb to the highest point in the area to watch for the first appearance of the Pleiades above the north-eastern horizon, a phenomenon that astronomers call *heliacal rising.* The appearance of the star cluster roughly coincides with the winter solstice (around 21 June), the shortest period of daylight for the year. This is when the Sun rises and sets at its northernmost position on the horizon (or southernmost, in the northern hemisphere), signifying the start of the new year in local cultures.

Farmers observe the number of stars in the cluster and how bright and big it is overall, to accurately forecast the timing and degree of coming rainfall essential for producing a successful potato harvest. If the cluster appears larger in size than in previous years, and more stars can be seen, farmers predict earlier and more abundant rainfall for the growing season. This occurs several months later, which generally runs from October to May. But if the cluster appears smaller and fewer stars are visible, then the people know that the season will be drier and they must prepare accordingly. This could mean

delaying the planting of potatoes by several weeks, as the tubers have shallow roots and require sufficient rain after planting. This makes them highly vulnerable to drought conditions. A miscalculation may result in a failed harvest.

This is basically the opposite of how Yamaji people apply the technique. Why is it that *clearer* skies mean more abundant rainfall? If moisture in the atmosphere impedes the clarity of the star cluster, does this not seem counterintuitive? The answer can be found by understanding the dynamics of airflow across the Andes, the mechanics of our atmosphere, and the ingenuity of Aymaran and Quechuan farmers.

In South America, wind generally f lows from east to west over the Amazon Basin. This flow pushes air from the Atlantic across the Amazonian rainforest, picking up moisture and humidity, which then falls as seasonal rain in the Andes. During the El Niño period, higher atmospheric pressure from the warmer waters of the eastern Pacific pushes high-altitude trade winds in the opposite direction over the summer months, from west to east. This drives the humid air away from the mountains, creating drier conditions.

In the tropics, El Niño forms a nearly invisible layer of cirrus cloud cover. The thickness of these ‘invisible’ clouds increases during this time (what meteorologists call ‘optical thickness’), obscuring the incoming starlight of the Pleiades. The cluster therefore appears dimmer and fewer of its stars are visible during years where El Niño is prominent. The relationship between the Pleiades and potato harvesting is so important, the Quechuan name for the star cluster is *Qullqa*, meaning ‘storehouse’, the place harvested crops are deposited and kept. This is derived from the Incan deity of the same name, who looked over the storage and preservation of seeds for the following growing season and is represented by the Pleiades.

Over centuries of careful observation, Aymaran and Quechuan farmers recognised the correlation between the size and clarity of Qullqa and the amount of rainfall during El Niño periods, demonstrating another clear example of how Indigenous science is developed locally. Scientists have known for some time that the Andes receives less rainfall during El Niño. But, as University of California researcher Benjamin Orlove noted, scientists did not make the connection between seasonal rainfall during El Niño, cirrus cloud cover and the visibility of the Pleiades—something the Aymaran and Quechuan peoples have long known. In fact, this forecasting system may go back hundreds of years or longer, possibly to the time of the Incan empire,

which existed for centuries until its collapse due to Spanish conquest in 1572.

Aymaran and Quechuan observations of the Pleiades have a deeper cultural significance than an application to food economics. Their appearance also culminates in a solstice festival, which kicks off on the evening of 23 June. This festival is celebrated across the Andes and has roots stretching back to the Incas. The Incan solstice festival was called *Inti Raymi'rata*, a Quechuan name meaning 'Sun festival', derived from *Inti* the Sun deity. *Inti Raymi*, as the festival is commonly known, originally started on the day after the winter solstice (around 22 June). As with many Indigenous cultures of the world, the heliacal rising of the Pleiades around the winter solstice signalled the start of the new year.

Similar solstice festivals marking the new year were celebrated in Ancient Greece and Rome. Midsummer (solstice) festivals celebrated across pagan Europe, including Germanic, Celtic and Slavic cultures, focused on bonfire celebrations. These fires were believed to ward off evil spirits, bring lovers together and increase warmth from the Sun for the remainder of the growing season, leading to a successful autumn harvest. When the Spanish colonised the Americas, the Catholic Church initially banned Indigenous festivals but eventually amalgamated them with European solstice celebrations into the modern Saint John the Baptist festival.

Flood-retreat agriculture

In certain areas, timing the annual flooding of rivers is essential for agricultural practices. This requires careful observations and correlations of star positions on the local horizon to the pulsating elevation of rivers and waterways. In Egypt, life in the arid desert landscape is heavily reliant on the annual flooding of the Nile River, a cycle that has been carefully observed since ancient times. This flooding is caused by the annual monsoon rains that fall from May to August, depositing life-sustaining water in the Ethiopian highlands, producing up to 90 per cent of the Nile's water. From ancient times to now, observations of key stars in northern Africa are critical for predicting the annual flooding of important rivers.

In the calendar of Ancient Egypt (3150 BCE–332 BCE), the year was divided into three seasons: *Akhet* ('Inundation', from June to September), *Peret* ('Growth', from October to January) and *Shemu* ('Harvest', from February to May). The annual flooding of the Nile occurred in the Akhet, a cycle that was

so predictable the Egyptians selected a very particular star to mark its arrival: *Sopdet* (Sirius), the brightest star in the sky. The flooding of the Nile can first be detected in early June, with river levels gradually rising until mid-July, when they increase quite significantly.

In Ancient Egypt, this is when Sopdet rose just before the Sun (around 23 July). The Nile continued to rise until early September, when it remained at a consistent level for approximately three weeks. On occasion, the Nile would rise a bit more in October, reaching its highest annual level before gradually dropping to its lowest point again in June. The heliacal (dawn) rise of Sopdet in July was used as an important annual indicator of when the more significant flooding of the Nile would occur. This was not an exact measurement, as flood levels varied by date each year, dependent on rainfall in the Ethiopian highlands. But it was a consistent marker, and one that the Egyptians positioned prominently in their calendar and astronomical toolkit.

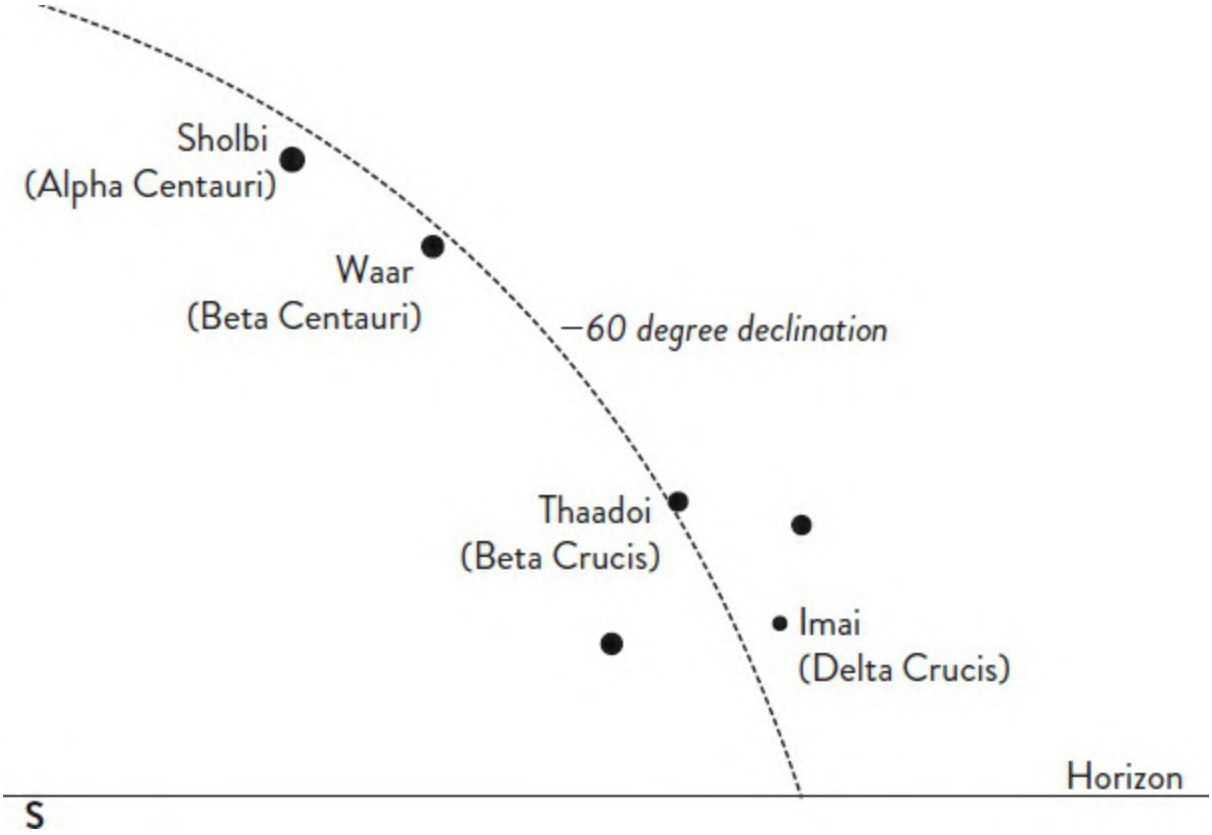
The monsoon rains that flood the Nile also flood other rivers in northern Africa, which are utilised by traditional communities today in similar ways to the Ancient Egyptians. They flood the Omo River, which empties into Lake Turkana, supplying 90 per cent of its inflow. This flooding is cyclic, going through a range of pulsations of differing levels, depending on the degree of rainfall upriver. The Mursi of southern Ethiopia utilise this annual cyclic flooding for a practice called ‘flood-retreat agriculture’. The Omo River (called *Waar* in the Mursi language) floods several times at regular intervals during the monsoon season. Mursi farmers plant crops of black-eyed peas, maize and sorghum within a few days of the final flood of the season. This timing is critical: if crops are planted too early, the flood will wash away the seeds; if the seeds are planted too late, the soil will be too dry for them to germinate.

As a part of the Mursi flood-prediction toolkit, farmers utilise a specific grouping of four stars that are spaced out in such a way that times of their setting at dusk correspond closely to the pulsations of the Omo’s floodwaters during the monsoon. The intervals of time between pulsations enable Mursi farmers to use these stars as a celestial clock. The monsoon season in Ethiopia starts in June and ends in September. The average monthly rainfall doubles from June to July, peaking in August, and dropping slightly in September before plummeting in October. During the height of the monsoon, heavy rain falls every couple of days. For comparison, light showers occur only once every week or two during the dry season.

The Mursi carefully selected four stars that form an arc across the sky: Alpha and Beta Centauri (the two Pointer stars in Centaurus) and Beta and Delta Crucis (the ‘left’ and ‘right’ stars of the Southern Cross; see ‘Bayer Designation’ in the Glossary to learn how astronomers name stars). Mursi names for these four stars are *Sholbi, Waar, Thaadoi* and *Imai*, respectively. These stars set vertically in the south-western sky at dusk, acting as a timepiece for each pulsation of flooding. When this starts, the people begin moving downriver in preparation for planting crops.

The Mursi named these stars as a method of committing that knowledge to memory; the names are based on their terrestrial links to the grass, the river and the tree petals. When Imai (Delta Crucis) sets below the horizon at dusk in late August, it signals the time when Waar (Omo River) rises high enough to flatten the imai grass that grows along its banks. Approximately nine days later, the floodwaters return but do not reach their full height. This is when Thaadoi (Beta Crucis) sets at dusk. Three weeks later, Waar (Beta Centauri) sets at dusk, marking when the river has reached its highest level, spilling into the forests along its bank. Sholbi (Alpha Centauri) sets at dusk by the start of October, indicating that the floodwaters will recede, carrying with them the petals of the acacia tree (also called *sholbi*). This is the time to plant crops along the waterfront.

To better understand why the Mursi selected these stars requires us to look at the positions of these stars in the sky relative to observers at that latitude. The stars’ selection was based on long-term observations. The four bright, easily visible *munyunya* (stars) that were chosen all have nearly the same declination (about –60 degrees) with distances between them corresponding closely to the timing of the flood pulsations of the Omo River. The angular distance between Imai and Thaadoi is about 4.3 degrees while the distance between Waar and Sholbi is nearly the same, at 4.5 degrees. The distance between Thaadoi and Waar (Beta Crucis and Beta Centauri) is about 9.5 degrees, or around double the average distance between each pair. When we calculate the days these stars set at dusk, we see that Imai sets (approximately) on 21 August, Thaadoi on 30 August, Waar on 21 September and Sholbi on 30 September.



Mursi stars (Pointers and Southern Cross) as seen from southern Ethiopia

Considering the fairly even angular distance between the stars and the time period between each star setting, we calculate that each star shifts towards the horizon at a rate of 0.44 degrees per day. Since the four stars share a similar declination, they move like the minute hand on an analogue clock, even though the bottom half of the clock face is below the horizon. If these stars were the same angular distances apart but had a collective declination north of –60 degrees, they would move too quickly to coincide with the river pulsations. If they were a bit further south, they would move too slowly.

Knowledge under threat

For the Mursi, failure to predict the Omo River floods and act accordingly would be disastrous. Droughts, magnified by the effects of climate change, are causing a gradual reduction in rainfall, affecting the timing of the floods. As a fundamental natural resource to many peoples in the region—including

the Mursi, Bodi, Dassanech, Karo, Kwegu and Nyangatom—crops and grass derived from the Omo floods provide food for over a quarter of a million people and their cattle. An ongoing drought in 2006 caused a delay in the flood season and reduced the rainfall normally experienced. October of that year saw heavy rainfall in the region, after what is normally the end of the flood season. This resulted in intense floods, with damaging effects catalysed by increasing deforestation in the region. Communities in the area suffered catastrophic loss and death: 456 people died and 20,000 were displaced. Due to the drought, annual floods ceased altogether by late 2009. Some farmers stopped planting and many of the traditional cultivation sites were abandoned. In a 2010 article published by non-profit group International Rivers, Mursi man Linasi explained how the pain and loss of the floods affected him and the community:

> There is no singing and dancing all along the Omo River now. The kids are quiet. We adults go into the shelter and sleep silently. We are too hungry. The big rains have been gone for three years, and now we come to the Omo and there is no water. We are hungry. We are people that eat from the Omo. Now that the floods are gone we have a big problem. We are afraid of death. We don't know what to do. Some people will die of hunger. We are praying for an answer. If the Omo floods are gone we will die.

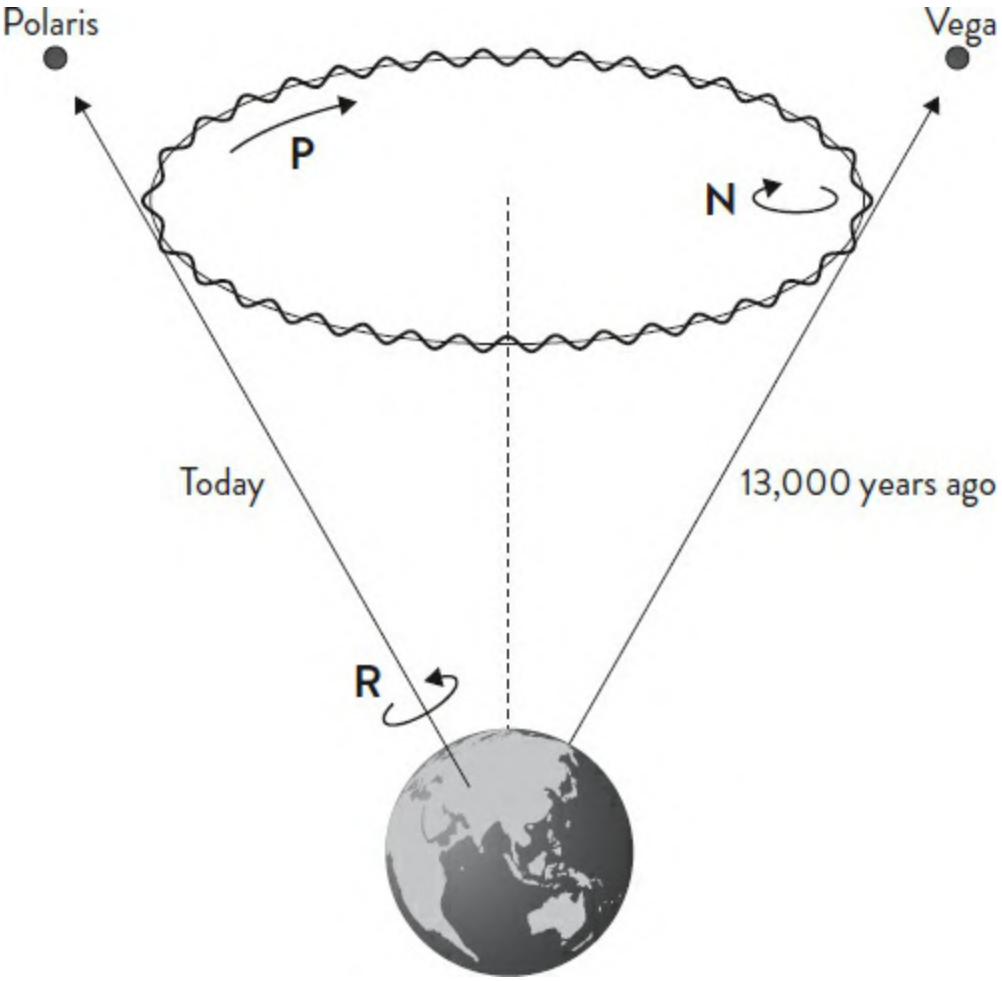
The erasure of these traditional practices by droughts, unexpected floods and the construction of dams upriver is leading to the potential loss of centuries of astronomical knowledge. Climate change is an ever-present and rapidly growing issue. Elders in the Torres Strait have been saying for years that the seasons are coming and going at odd and unusual times, sometimes arriving weeks early or late. This is having a devastating impact on wildlife, as well as traditional gardening, hunting and fishing practices. The synchronicity between the stars and the changing of seasons is shifting to such a degree that, eventually, these observations may have little or no practical application without a complete overhaul of the knowledge systems.

The shifting stars

Knowledge systems are dynamic and change over time. It is necessary that they do so since both the stars and the climate gradually shift over long periods of time. Evidence shows that for tens of thousands of years, First Peoples have selected stars to denote seasonal change. And this in itself is an evolving process.

The Earth spins on its axis and orbits the Sun, while the Moon, planets and Sun all play a gravitational tug of war with our world. This causes the Earth to slowly wobble and shift over the millennia, which in turn affects climates and seasons, as well as where and when the stars will rise and set in the sky. But these changes are slow and gradual. The wobble of the Earth's axis is called *precession*, and it looks much like the wobbling of a child's spinning top. The handle of the top rotates in a large circle as it spins, just as the poles of the Earth trace out a large circle every 26,000 years.

The direction of the Earth's poles also sways up and down slightly as the axis precesses, meaning the angle of the planet changes as it wobbles. A spinning top does the same thing. Astronomers call this *nutation.* The stars themselves also change position relative to each other as they orbit the centre of our galaxy, a term Western astronomers call *proper motion.* Some stars move faster than others, and their direction of motion can vary from star to star; they are not all moving in the same direction. Stars are objects in three-dimensional space, not points on a dome. They can move towards or away from us, as well as 'side to side' in the sky. This can affect how bright they are over time.



Precession (P) and nutation (N) for a rotating body (R). The wavy line represents nutation; the big circle shows precession.

A few thousand years ago, Polaris was not the north star, and the setting stars of the Southern Cross would not have been useful for timing the pulsating floods of the Omo River. These effects also tell us that a constellation familiar to us today would have looked quite different in the distant past. Because of this, the connection between where and when a star will rise or set at a certain time of year is limited by a window in time. The window is bound by the *terminus post quem* (‘limit after which’) and *terminus ante quem* (‘limit before which’) an event could have occurred.

North-west Victoria is home to the malleefowl (*Leipoa ocellata*), a mound-building bird the size of a chicken. It is called Neilloan in the Wergaia language and is associated with the star Vega. When Neilloan (Vega) rises at dusk in mid-August, the birds begin preparing their nests. When it is high in

the sky in mid-September, they begin laying their eggs. When Vega sets in late October, the first chicks of the season begin hatching.

Vega was chosen by the Wergaia people because its position in the sky closely corresponds to the seasonal behaviours of the animal. But that has not always been the case. If you go back about 8000 years, Vega would have had such a northerly declination that it would not have been visible in the sky at all. That is the terminus post quem of the connection between Vega and the malleefowl. Before that time, the connection would have made no sense, as the star was not visible. This does not even include changes in the environment or climate that far back.

We see that First Peoples 10,000 or 20,000 years ago would have made very different connections between the land and sky to what we see today. We find evidence of this in Aboriginal traditions from Tasmania. In the early 1800s, Elders described the presence of a bright star close to the south celestial pole, called Moinee, at a time when Tasmania was still connected to mainland Australia by land. The traditions describe the oceans rising until the island of Tasmania was created.

Using a map drawn by an Elder, it is clear that Moinee is the star Canopus. By calculating the precession of the equinoxes and the star's proper motion, we can determine that Moinee reached its southernmost declination in the sky around 12,000 years ago. Geological data reveal that the Bass Strait, between Tasmania and Victoria, was also formed by rising seas about 12,000 years ago. This means the oral tradition's terminus ante quem is where those lines of evidence meet: 12,000 years ago.

As we can see, neither the stars nor the knowledge systems that describe them are static in time. They are both dynamic!

CHAPTER 7

The Variable Stars

‘The strongest brother leant down with his spear and pulled his younger brother up to the sky to become the star Western astronomers call Saiph, in Orion. The father, who had been badly injured, went up into the sky as the star Betelgeuse, which pulsates slowly.’

—Professor Dennis Foley, Gaimariagal Traditional Custodian

In 350 BCE, Greek philosopher Aristotle taught that the heavens were unchanging and the stars invariable. The philosophical position of the day was that the heavens were perfect and static—an idea that remained a cornerstone of Western religion *and* astronomy for nearly two millennia.

In the sixteenth century, accepted models of cosmology did not include any mention of stars changing in brightness, aside from the occasional ‘guest star’ that appeared in the night sky. According to historians of science, it was not until 1596 that the first recurring variable star was identified (that is, it was recorded in writing). On 3 August of that year, German pastor David Fabricius noted that the star Omicron Ceti appeared brighter than normal. By late August, the star brightened by one full magnitude before completely fading from view in October. This posed another major challenge to the Aristotelian position: what could explain the peculiar behaviour of Omicron Ceti if the stars are invariable and unchanging?

In modern astrophysical terms, Omicron Ceti is a binary system consisting of a red-giant star and a white-dwarf star. The red giant pulsates, changing in brightness from magnitude 2.0 to 10.1, making it appear as a reasonably bright star before fading to invisibility, then brightening again over the course of 332 days. At the time, there was no place in Western science for recurring variable stars. Unaware of what he was seeing, Fabricius recorded the star as a *nova* (‘new star’) after all signs of the star had vanished. In 1609, he noticed that Omicron Ceti had reappeared and brightened again, bringing into question its classification as a nova. The star was officially recognised as a

variable star when it was named Mira by Frisian astronomer Johannes Holwarda in 1662, who had calculated the period of the star's variability and is credited as its discoverer.

By the mid-nineteenth century, several variable stars had been identified by Western astronomers. As part of a systematic search for additional examples, Englishman Sir John Herschel began conducting observations from the Cape of Good Hope, South Africa, in 1836. He kept journals in which he compared the relative brightness of stars in a particular region of the sky and listed them by magnitude. The idea was simple: if the stars did not change in brightness, the order of stars on the list would remain the same. Herschel kept records for a few years, which revealed that the bright red-giant star Betelgeuse in Orion sometimes appears brighter than, then equal to, then fainter than some of the nearby bright stars.

After returning to England, Herschel forgot about this discovery. In 1839, he looked back over his notes from 1836, remembering that he had discovered something about Betelgeuse at the time. His records showing that the star changed in brightness over time were hailed as a breakthrough for Western science. Herschel presented his observations at the January 1840 meeting of the Royal Astronomical Society in London, which led to the gradual development of a new branch of astrophysics. Historians of science credit Sir John Herschel as the discoverer of the red-giant star's pulsating variability, placing him in the canon of historical figures whose genius contributed to major scientific discoveries. But was he really the first to observe and record the variability of Betelgeuse?

Across Australia, Aboriginal traditions describe a relationship between groups of stars in the Western constellations of Orion and Taurus. Taurus is famous for its two bright star clusters: the V–shaped Hyades and the Pleiades ('Seven Sisters'). Orion, the hunter, traces the outline of a man, including three conspicuous stars in a nearly straight line, comprising his belt.

In the early twentieth century, Irishwoman Daisy Bates spent nineteen years living with Aboriginal people at the Ooldea Mission in the Great Victoria Desert of South Australia. During that time, she kept journals about the local Aboriginal peoples' stories and language, which she published as a series of newspaper articles in *The Australasian* throughout the 1920s. These articles included some of the local star stories, which Bates was able to appreciate, writing that 'Here in the bright, still evenings, I studied the skies, astronomy being an old love of mine, and compiled Aboriginal mythologies,

many of them as poetic and beautiful as are the starry mythologies of the Greeks.'

One story in particular contained something quite remarkable—something that would challenge the history of science and overturn the position of Herschel's first discovery.

The humiliation of Nyeeruna

Aboriginal people in Kokatha Country of the Great Victoria Desert maintain traditions about *Nyeeruna*, a man in the stars comprising the Western constellation Orion. Like the Greek Orion, Nyeeruna is a skilled hunter, vain and full of himself. He proudly dons a feathered headdress, a string belt and whitened tassel (represented by the belt and 'scabbard' stars of Orion), holds a club in his right hand (the star Betelgeuse) and covers his body in red ochre. But Nyeeruna is not a gentleman. He is a womaniser and preys on the young Yugarilya sisters of the Pleiades. The sisters are timid and fearful of the aggressive Nyeeruna, who chases them across the sky each night. He tries to be clever and use trickery to catch them, leaving food out for the girls and hiding nearby. But they are cleverer than Nyeeruna and don't fall for his ploy. Instead, dingoes eat the food.

The eldest sister, Kambugudha, is protective of her younger siblings and knows Nyeeruna's inappropriate intentions. She also knows that behind his arrogant façade, Nyeeruna is really a coward. Kambugudha, who is represented by the Hyades star cluster, is not afraid of him and stands before him, taunting and mocking while blocking him from reaching her young sisters. She is so contemptuous of him that she places a row of dingo puppies between Nyeeruna and herself to keep him away (the arc of stars seen as Orion's shield). Her mockery and use of puppies rather than adult dingoes are deliberate acts of humiliation.

Kambugudha's taunts infuriate Nyeeruna, and his desire for the Yugarilya sisters only grows more intense. Nyeeruna begins to chant and produce fire magic in the club he holds in his right hand (the star Betelgeuse). This makes his hand grow bright and hot, and sparks emanate from his body. Seeing this terrifies the Yugarilya sisters, who are of the Mingari (thorny devil lizard, *Moloch horridus*) totem. They morph into the small lizards to escape the interest of Nyeeruna. Kambugudha counters him by producing fire magic in her left foot (the star Aldebaran). She advances towards Nyeeruna, lifting her

leg and kicking fire towards him. This frightens the cowardly Nyeeruna, and his fire magic dissipates.

Eventually, Nyeeruna's lust returns with force, and he again gathers fire magic in his right hand. Kambugudha calls on *Babba* (the father dingo), who rushes in and attacks Nyeeruna, grabbing and shaking him. While Babba is shaking Nyeeruna to the east and west, the eldest sister laughs and points her red foot mockingly at the womaniser. Her young sisters hide their heads under lumps on their necks, just as the thorny devil lizards do when frightened. The surrounding stars all jeer at Nyeeruna. They twinkle with laughter and stand ready to assist Kambugudha. In his humiliation, Nyeeruna's fire magic dissipates again.

Different versions and variations of this story are found across Central Australia. Each is slightly different, as are the names of characters in the narrative, as they reflect the different languages of cultures across the region. But they are all linked together through a Songline that stretches across the continental interior, connecting the story in the sky with features in the landscape and important ceremonies. This Songline was central to a popular art exhibition about the sisters of the Pleiades being pursued by the man in Orion that debuted in 2017 at the National Museum of Australia in Canberra, titled *Songlines: Tracking the Seven Sisters.*

Similarly, Classical Greek traditions describe Orion as a vain hunter who pursues the Seven Sisters of the Pleiades. In the sky, Orion is prevented from reaching the stars by Taurus, the bull. The V-shape of the Hyades star cluster signifies the horns of the bull (though this was not described in Greek traditions, but rather developed to make sense of the astronomical orientation of these stars). In the Kokatha traditions recorded by Bates, we find many similarities. Even though the stars familiar to the Greeks are seen 'upside down' in Australia, the Kokatha people say Nyeeruna is upside down in the sky—in the same orientation as his Greek counterpart.

This is the same for the 'All Father' creation ancestor in Wiradjuri traditions of central New South Wales. The stars Betelgeuse and Bellatrix represent his right and left hands, and Rigel and Saiph are his feet. You can see Kambugudha in the sky as the Hyades star cluster. The V-shape of the Hyades, which represents the horns of the bull in Greek traditions, traces out Kambugudha's legs in Kokatha traditions.

The similarities between Aboriginal traditions and Classical Greek mythology drew the attention of newspaper readers in the 1920s. One reader,

signing off as ‘Canopus’, wrote to the editor about Daisy Bates’ article, claiming that the Aboriginal traditions must have been influenced by, or based on, the Greek traditions brought to Australia during British colonisation. Bates countered these comments by stating that this was known to the people much earlier, with no outside influence.

What we find in this story are layers of knowledge based on careful observations of these stars. The pursuit of the Yugarilya sisters by Nyeeruna describes the *diurnal* (east to west) motion of the stars as they move across the sky each night. The red colour of the fire magic in Nyeeruna’s right hand and Kambugudha’s left foot is reflected in the colours of the associated bright red stars Betelgeuse and Aldebaran. Even the rising of these stars at dusk is reflected in the story’s association with the thorny devil lizard. The eggs of the lizards begin hatching in December, when the Yugarilya sisters rise at dusk.

In her journals, Daisy Bates seemingly had difficulty explaining how the stars brighten and fade over time. Bates attributed the changing brightness of the stars to ‘emissions from nebulae’, though no astrophysical basis exists for this description. To be fair, she may have simply not known about this as it was not common knowledge that stars change in brightness back then—or even now. Rather than ‘emissions from nebulae’, what the Aboriginal people were describing was the variable nature of these stars, something that escaped the attention of anthropologists and astronomers for more than 80 years.

The taboo of Waiyungari

The Ngarrindjeri people of the Coorong in South Australia maintain an oral tradition about Waiyungari (meaning ‘red man’)—a young man going through *Kaindjani* (initiation). During this time, he is considered *Ngarambi*, a sacred state of being in which he is subject to strict prohibitions. He is covered in red ochre (hence his name) and must fast, go without clothing, and have no contact with other initiates or women. Violating this Law could result in serious reprimand for the offender and their relatives.

As the (highly abridged) story goes, Waiyungari was walking along the water’s edge one day and knelt down to get a drink, using a reed as a straw. As he drank, some of the red ochre fell from his body into the water. It flowed downstream, catching the attention of two women. After searching for the source of the ochre, they saw Waiyungari. They found him extremely

attractive and secretly followed him to his house. When Waiyungari retired for the night, the women morphed into emus, making sounds that drew the initiate from his home. He rushed outside, ready to spear the ‘emus’, when they changed back into human form. The women wrapped their arms around Waiyungari and asked him to take them as wives. He willingly consented.

Through this act, Waiyungari broke Ngarambi Law. But the situation was much worse. Unbeknown to him, the women were the wives of his older brother, Nepeli. Waiyungari’s mother had witnessed the incident and was enraged. She told Nepeli that his wives had betrayed him, and his brother had broken a sacred taboo.

In a state of fury, Nepeli set Waiyungari’s house ablaze while the trio slept inside. The smoke woke them, and they quickly escaped, running along the riverbank. Knowing they faced death as punishment, Waiyungari tied a rope to a spear and cast it into the Milky Way. He pulled himself and the women into Wyirrewarre (sky-world) where he became a bright red star, signifying the colour of his ochred body. The two women went up to become stars flanking him on either side. He later pulled his canoe up into the Milky Way. On the land, you can also see their hut as a mound of limestone, located at Pulluwewal, near Point Macleay, South Australia.

In Ngarrindjeri traditions, the trio sit in his canoe in the Milky Way with the celestial emu to the west. Occasionally, Waiyungari brightens, getting ‘hotter’. This represents his forbidden desires, and serves as a warning to initiates that they must obey traditional Law. With a clear indication that the star brightens and fades repeatedly over time, why was this tradition not considered by scientists of the day? Or even in the decades since?

One reason is because the star representing Waiyungari was misidentified as the planet Mars by early ethnographers. This highlights the problem of researchers trying to record Indigenous star knowledge when they themselves have a limited knowledge of the stars. Discussions and consultations between anthropologists over the next century did nothing to correct this error, which was published in multiple popular books and went unchecked until 2017. This also highlights the need to critically consider ethnographic records written by colonists and non-Indigenous people.

The first written record of the Waiyungari tradition was published by Dresden missionary Heinrich Meyer in 1843, but that version did not identify the stars representing Waiyungari or the two women. In 1935, anthropologist Norman Tindale published a version of the Waiyungari story that he was told

by Elders of two Ngarrindjeri clans near Lake Alexandria in South Australia. He thought Waiyungari was the planet Mars.

Tindale attributed the occasional brightening of Waiyungari to the planet's changing brightness as seen from Earth as they orbit the Sun. Sometimes Mars is close to us, and sometimes it is on the other side of the Solar System. This means its brightness varies from magnitude −2.91 when it is closest, to magnitude +1.84 when it is the furthest away. Because the stellar magnitude scale is logarithmic, Mars is nearly 80 times fainter at its lowest magnitude than at its brightest.

Although Tindale was convinced Waiyungari was Mars, he was not sure which celestial objects represented the two women. He contacted George Dodwell, the South Australian Government astronomer, to help. Dodwell suggested they were the planets Jupiter and Venus, but only did so to fit with the supposed 'planetary' theme. The suggestion was not consistent with any of the elements described in the Waiyungari traditions.

Around the same time Tindale was trying to understand celestial objects in the Waiyungari traditions, anthropologists Ronald and Catherine Berndt were collaborating with Ngarrindjeri/Yaraldi communities, documenting their version of the Waiyungari tradition. Just like Tindale, the Berndts identified Waiyungari as the planet Mars. They wrote that Waiyungari 'dominates the evening skies in September', acting as a seasonal marker for the arrival of spring.

Using anthropological frameworks, they described the red man as the personification of sexual prowess and fertility. When Waiyungari appears in the sky at his brightest, the sexual feelings of men and women are enhanced. This reminds young initiates to fight their hormonal urges or suffer the severe consequences of breaking Ngarambi taboo. In this case, Waiyungari serves not only as a seasonal marker but also as a memory aid for the people to remember the importance of traditional Law.

How can Mars, a planet, always appear high in the sky every spring? It can't. As discussed in Chapter 4: The Wandering Stars, planets constantly move back and forth across the background constellations of the zodiac as they orbit the Sun. Mars will not always appear in the Milky Way at a given time of year, nor will it always appear in the stellar canoe or lie east of the celestial emu. No planet will. It is clear from the traditions that Waiyungari is not a planet but a star.

If Waiyungari is a star, then which one is he? Ngarrindjeri traditions

describe Waiyungari ascending into the sky to become a bright red star in the Milky Way, with the two women flanking him. The trio sits in the celestial canoe, represented by the stars of Scorpius, with the celestial emu to the west. They are high in the sky every September at the start of spring. With this information, there is only one explanation that fits: Waiyungari is the bright red star Antares and the two women are the stars Tau Scorpii and Sigma Scorpii, one on either side. Curiously, the Berndts included a star map in their book that showed this! Yet they and other anthropologists still maintained that Waiyungari was Mars.

The three stars and their relationship to each other are described in similar terms by Aboriginal communities across Australia, and even around the world. Several communities describe Antares as a man or woman with the stars Tau and Sigma Scorpii representing spouses or siblings who travel with them. They are featured in Wergaia traditions of north-west Victoria, where Antares is the male figure *Djuit*, and Tau and Sigma Scorpii are his wives. In Wurundjeri traditions of Melbourne, Antares is *Nurong*, the brother of the creation ancestor *Bunjil*. Tau and Sigma Scorpii are his wives. In Aotearoa/New Zealand, Professor Rangi Mātāmua teaches that Antares is *Rehua*, the chief of the stars, and his two wives are *Ruhiterangi* (Sigma Scorpii) and *Whakaonge Kai* (Tau Scorpii).

Back in Australia, the Arrernte traditions from the Central Desert teach that these stars represent a trio of women avoiding the advances of a group of men. Just like Waiyungari, the woman represented by Antares is covered in red ochre. The narrative about Waiyungari's actions is mirrored in the traditions of other Aboriginal cultures across the continent. In Aboriginal traditions from the Clarence River in north-eastern New South Wales, a man named Karambal abducted a woman. Fearing retribution, he hid in a tree. The woman's angry husband found Karambal hiding and set the tree ablaze. Karambal ascended into the sky as smoke to become the star Aldebaran.

It is somewhat ironic that Western anthropologists confused Antares with Mars in the traditions of Waiyungari. The planet Mars (named for the Roman god of war) is associated with Antares in Classical mythology. The name Antares comes from the Ancient Greek word ’Αντάρης, meaning 'rival to Ares'. Ares was the Greek god of war, the earlier counterpart to Mars. Both objects appear bright red in the sky, and because the ecliptic passes close to Antares, Mars sometimes passes very close to the star. They are rivals, fighting for dominance in the night sky. As Wiradjuri astrophysicist Kirsten

Banks pointed out, Antares basically means ‘not Mars’! Had the anthropologists known about the Greek traditions in which Western astronomy is so deeply steeped, they might have picked up this connection. But their lack of astronomical knowledge means they were unaware that a planet is a poor seasonal indicator. Besides, Mars did not fit any of the descriptions of Waiyungari other than being bright red.

Waiyungari being Antares, not Mars, matters a great deal when recognising the scientific observations woven into the story.

Important revelations

In astrophysical terms, Antares is remarkable, being one of the brightest and most massive stars in our galactic neighbourhood. One day it will explode as a supernova. Although it looks like a single star to our eyes, it is actually a binary (two-star) system. Astrophysical studies show that Antares is 550 light years away, meaning it would take 550 years travelling at the speed of light (300,000 kilometres per second) to reach it. The larger of the two stars, Antares A, is twelve times the mass of our Sun, 700 times bigger and nearly 100,000 times brighter. The smaller of the pair, Antares B, is seven times bigger and five times more massive than our Sun. This is a whopping giant of a system.

Antares A is an irregular, long-term variable star. This means its brightness changes over time but doesn’t follow a precise pattern. Astrophysicists studying the star’s variability found several cycles of fluctuation in its brightness, but the primary change from magnitude +0.6 to +1.6 occurs on a cycle of roughly 4.5 years. A brightness change of one magnitude means the star is 2.5 times brighter at its peak than when it is at its dimmest. This is easily noticeable when comparing it to the brightness of nearby stars. Although Antares will come back to the same location in the sky each spring, it will appear to be noticeably brighter only every few years—not annually. Ngarrindjeri people long ago observed the variable nature of Antares and incorporated it into their oral traditions.

Mars and Antares are age-old rivals, and ethnographers regularly confuse the two. But it’s hard to imagine two objects less alike. From Earth, they appear to be similar in brightness and colour, both fighting for dominance in the Milky Way and occasionally coming very close to one another. Mars is red because it is covered in iron oxide (rust), while Antares is red because it

burns red hot at 3500 degrees Celsius. On Earth we see them as similar in brightness because Mars is so close and Antares is so far away (if the maximum distance between Mars and Earth were 1 cm, Antares would be 130 kilometres away). When you compare their actual sizes, the result is gobsmacking. If Mars were the size of a cricket ball, Antares would be nearly as big as the Earth. Even their ages are strikingly dissimilar. Mars, like the rest of the Solar System, is about 4.3 billion years old. The Antares system formed just 11 *million* years ago. Antares didn't exist when dinosaurs walked the Earth. It formed 55 million years after their extinction.

The star Betelgeuse, which is described as the fire-magic-wielding right hand of Nyeeruna, is also a red-giant variable star. It shows semi-regular pulsations in its brightness, changing from magnitude 0.0 to 1.6 over a period of roughly 400 days. Astrophysicists found a secondary, smaller pulsation that lasts 2100 days. Like Antares, Betelgeuse is one of the largest stars in our galactic neighbourhood, being more than 800 times the diameter of the Sun. It formed about 10 million years ago and is 700 light years from Earth. Despite historians of science crediting John Herschel with the formal discovery of this star's variability, we see from the Nyeeruna traditions that the Aboriginal people across the deserts of Australia had long ago observed the phenomenon and incorporated it into their knowledge systems.

It is the third star discussed here that highlights the keen observational skills of Aboriginal people. Like Antares and Betelgeuse, the star Aldebaran is also a red giant. It is 44 times the size of our Sun and is relatively nearby, being only 65 light years away. It is also a pulsating variable star, but its changes in brightness are much smaller than those of the other two red giants. So small, in fact, that they are at the threshold of what we can detect with the unaided eye. Astrophysical research also shows that Aldebaran's pulsations are very irregular. The star can go through rapid changes in brightness and then spend a considerable time not changing at all. For many years, these changes were believed by astrophysicists to lie below the threshold of human visibility. If this was the case, how could Aboriginal people have noticed the fire magic in the left foot of Kambugudha brighten and dim?

This was a problem that Trevor Leaman and I pondered in 2013 when we began following the lead of Serena Fredrick, a scholar who argued in her 2008 master's thesis that the Nyeeruna traditions are describing the variability of Betelgeuse. If the evidence showed that the variations in Aldebaran's brightness were lower than what people could see, are the

Aboriginal traditions wrong or are the astrophysicists wrong? We knew that the Aboriginal traditions reflect deep-time observations of the cosmos, so going with the latter made perfect sense, but we had to check. That turned out to be the case, serving as yet another example of how Indigenous Knowledges are capable of guiding Western science if scientists are willing to give them a chance.

New data was later published that showed the range of Aldebaran's brightness changes is greater than originally thought. Long-term telescopic studies show that the star irregularly ranges from magnitude 0.75 to 0.95. This change is two-tenths of a magnitude. For most experienced star observers, the lower threshold of a person's ability to detect these changes is one-tenth of a magnitude, or roughly the difference in brightness between the stars Alnilam (magnitude 1.69) and Alnitak (magnitude 1.77) in Orion's belt. Most experienced observers can tell Alnilam is slightly brighter than Alnitak, made easier by the stars being close to each other for more accurate comparison. Observing a star's brightness varying in such a small amount over a period of years is truly significant. The fact that modern astronomy has only recently been able to recognise Aldebaran's visual variability is a testament to Indigenous observational techniques and the power of oral tradition.

But it does not end there. The tradition of Nyeeruna reveals more than Betelgeuse and Aldebaran brightening and fading periodically over time. When Kambugudha counters the fire magic of Nyeeruna, his magic dissipates in his humiliation and the star dims, as does the fire magic in her foot. But Nyeeruna's fire magic returns. This time, Kambugudha is not prepared to counter Nyeeruna and therefore calls on Babba to step in and handle Nyeeruna's unruliness. After this interaction, Nyeeruna's fire magic again dissipates. This implies that the period of Betelgeuse's variability is more frequent than that of Aldebaran. It seems the people observed the two stars' variability *and* the relative periods of this variability.

Traditions about Nyeeruna, Kambugudha and Waiyungari are clear examples of First Peoples observing variable stars and encoding this information into oral tradition. This went unnoticed for decades because the ethnographers who recorded the knowledge did not have the astronomical training necessary to make the connection. It highlights the need for information recorded in archives to be considered carefully and critically.

Shortly after publishing a paper on the topic, Bob Fuller called and told me

about a tradition only recently shared with him by Professor Dennis Foley, a Gaimariagal man and academic at the University of Canberra. The traditional story is about the stars in Orion, which Professor Foley gave us permission to share. It originates from the Ngarigo people of the Snowy Mountains, southwest of Canberra, but is also shared by the Gaimariagal community.

> The Ngarigo were once a large community but were pushed back into the mountain peaks by people moving upstream from the Murray River. At one point, only six people remained: a father, his two sons and his three daughters. The daughters were considered very beautiful, with ice in their hair. To save themselves, the eldest brother threw his three sisters into the sky, where they became the three bright blue stars in Orion's belt. Their icy hair can be seen today as the twinkling of those stars. The strongest brother jumped up to become the star Rigel [Beta Orionis]. He leaned down with his spear and pulled his younger brother up to become the star Saiph [Kappa Orionis]. The father, who had been badly injured, went up into the sky as the red star in Orion [Betelgeuse], which *pulsates slowly.* [Emphasis added]

Betelgeuse has the final say

When I published research showing that that Aboriginal people had observed pulsating variable stars in *The Australian Journal of Anthropology* in 2018, the news spread rapidly. I initially thought the astronomical community might not accept these results, but that was not the case. Astrophysicists celebrated the news, including the president of The American Association of Variable Star Observers—the leading global organisation dedicated to research on the topic.

But for some, the idea that Aboriginal people observed a phenomenon that Western astronomers had missed for centuries was going too far. Detractors said it was impossible. They argued that Aboriginal people did not have the observational skills or written records that were supposedly necessary to make such a discovery. This revealed a deep level of misunderstanding about the nature of orality and the skills of people who had been carefully watching the skies for tens of thousands of years.

This sparked Professor Bradley Schaefer, an award-winning astrophysicist who spent part of his career testing claims of ancient stellar observations, to critically review the work and put these claims to the test. He published his conclusions in a 2018 issue of the *Journal of Astronomical History and Heritage* with the title of his paper summing up his concluding thoughts: 'Yes, Aboriginal Australians can and did discover the variability of Betelgeuse.' Soon after, it was clear that academic arguments would no longer be necessary in proving this point. By an amazing coincidence, the

star was about to demonstrate its variability for the whole world to see.

In late 2019, Betelgeuse began to dim rapidly, sending waves of surprise throughout the astronomical community and making global headlines. It started to dim in October, and by December it had faded from magnitude 0.5 to 1.5 (a factor of 2.5 times), dropping in rank from the eleventh brightest star in the sky to the twenty-fourth. This made it dimmer than the nearby star Aldebaran (the left foot of Kambugudha). It was the faintest the star had been seen in the last century. Global media sensationalised the event, focusing on the highly unlikely possibility that the star might imminently explode as a supernova. This fuelled a series of popular science articles, many of which featured the Aboriginal traditions describing the star's variability. Betelgeuse showed the world what Aboriginal people had already long known. And it silenced the doubters who said such a thing could not be noticed by anyone not trained in the techniques of Western astronomy.

In June 2021, a team of astronomers led by Dr Miguel Montargès announced that the reason Betelgeuse dimmed in this instance is because a dark spot formed on the star (just like a sunspot), combined with gas the star previously ejected into space cooling and condensing as dust, which acted like a dark cloud between us and the star. Betelgeuse hasn't exploded as a supernova (yet!) but it did bring attention to one of the most famous and well-known stars in the sky, and generated a lot of interest about the physics of exploding stars.

It was also a perfect opportunity to remind the world that Aboriginal people had clearly and unmistakably observed the changing brightness of this enigmatic star long before the phenomenon was known to Western science. It also made astrophysicists consider that these variations in brightness may be more frequent than previously known, as documented records of the star's brightness do not go back that far … only a bit over a hundred years.

Changing the history of astronomy

Astrophysicists today know that many stars in the sky change in brightness over time. Most of these changes are simply too small for our eyes to detect, or they occur over time periods too long for us to notice. But a handful of stars, such as Betelgeuse and Aldebaran, do vary enough to be noticeable to the unaided eye. The description in the story about those two stars getting 'hotter and brighter' as Nyeeruna and Kambugudha battled each other with

fire magic demonstrates something extremely important: Aboriginal people had long ago observed and noted changes in the brightness of these stars and incorporated them into their oral traditions.

Despite the accolades the Classical Greeks receive for laying the foundations of Western science, they never once mentioned variable stars in their mythology or philosophy. It seems this was prevented by the staunch adherence to their philosophical positions on nature, which superseded any observable evidence that contradicted it.

The observations by Aboriginal people also demonstrate the ability to maintain a body of knowledge about these stars' variable nature and pass it down through oral tradition. It is unclear what specific techniques Aboriginal people used to observe the change in brightness of these stars, but it may well have been the technique of comparing the brightness of nearby stars that Herschel used. It's so effective, amateur astronomers still use it today. This raises an important question: if Aboriginal people in Australia observed this phenomenon, did other cultures of the world do the same?

For over a century, some scholars argued that cultures in the ancient past observed and recorded variable stars either in their oral traditions or in their systems of writing. Many of these arguments are circumstantial; few are definitive. Earlier, we discussed Mira, a variable star whose discovery is credited to David Fabricius. Another conspicuous variable star that changes brightness on a scale of days is Algol (Beta Persei). Algol is a triple-star system. In astrophysical terms, the two larger stars take turns moving in front of each other as seen from Earth, with one eclipsing the other every 2.86 days. This causes the combined light of the system to dim from magnitude 2.1 to 3.4 for about ten hours. Because Mira and Algol are arguably the most noticeably variable stars, claims about ancient observations of their changing nature have been put forth by scholars examining astronomical systems of knowledge in ancient India, Babylonia and China.

In 1905, Kalinath Mukherji, an Indian scholar who studied ancient Vedic and Hindu astronomy, published the book *Popular Hindu Astronomy*, in which he concluded that Hindus had described the variable stars Mira (*Kamarupa-tara*, meaning 'changing at its pleasure') and Algol (*Mayavati*, meaning 'the changeful'). Mukherji argued that the traditions about their changeable nature in stories were representations of their variable brightness.

In 1935, Johann Schaumberger argued that the variable nature of Mira was known to the ancient Babylonians. In 1977, Edward Schafer published the

book *Pacing the Void*, arguing that ancient Chinese astronomers (*c.* 205 BCE) noted the variable nature of Algol (*Tsi-Chi*) through its astrological implication as an omen of good or evil, and relating to death. A year later, Jorge Sahade and Frank Wood published the book *Interacting Binary Stars* in which they make the same argument.

In 1996, physicist Stephen Wilk suggested that ancient cultures of pre-Classical Greece observed the variable nature of the stars Algol, Mira, Delta Cephei and Gamma Cassiopeiae. Delta Cephi is a four-star system that varies from magnitude 3.48 to 4.37. The main star in the system pulsates with a period of about 5.4 days, making it one of the few variable stars careful observers can see change each week. Gamma Cassiopeiae is an irregular, eruptive blue-giant star that changes from magnitude 1.6 to 3.0, brightening as it ejects shells of debris into space and dimming as that debris cools and blocks the star's light.

Both star systems are in the northern skies and are not visible from much of the southern hemisphere. Wilk's arguments focused on interpretative mythology. He argued that the stars' variability, and the periods of this variation, are related to myths linking these stars to Perseus and the Gorgon sisters of Greek mythology: Stheno, Euryale and Medusa. He argues that the number of sisters is consistent with the number of days (2.86) that pass before Algol dips in brightness. He proposed other connections, but they are circumstantial.

Wilk's interest in the idea that variable stars were described in ancient traditions of the world led him to research the subject in more depth. In 1999, he published a follow-up paper arguing that the variability of Betelgeuse was described in the traditions of the Ancient Greeks, the Tupi of northern Brazil, and the Lakota of the North American plains. In these cultures, Betelgeuse represents blood flowing from a severed limb. Wilk speculated that the long-term change in the star's brightness represented blood dripping and flowing from the stump. The flickering of this bright red star as it twinkles seems a more apt representation of 'flowing blood' than slow changes in brightness over several years.

Aside from the clear descriptions of variable stars in Aboriginal traditions of Australia, much of the research in this area is rather speculative. Is there a more definitive example of ancient peoples observing and recording variable stars? In 2008, astrophysicists Dr Lauri Jetsu and Dr Sebastian Porceddu led a team that suggested that the Ancient Egyptians recognised that the star

Algol periodically changes in brightness for a short time, and recorded the period of this variability in an astrological calendar.

That's right: astro*logical.*

The *Cairo Calendar* (also known as the *Calendar of Lucky and Unlucky Days*), is dated to 1244–1163 BCE and features a mixture of calendric and astrological predictions that provides prognoses for each day of the year, noting if those days are considered 'good' or 'evil'. In 2018, the Jetsu and Porceddu team used statistical methods to confirm that the period of Algol's dips in brightness were recorded in the *Cairo Calendar*, as well as demonstrating *how* the Egyptian scribes were able to accomplish this. This work led to new discoveries in modern astrophysics.

In the Egyptian records, the calculated duration of Algol's transit as described in the records was slightly shorter than today. Astrophysicists observing the binary stars were able to calculate the orbital mechanics of the system, showing that they have been gradually moving apart. This means that thousands of years ago the stars were a bit closer to one another, orbiting each other at a faster rate. This explains why the period of the dip was shorter than it is today, providing solid evidence that the ancient Egyptians had indeed observed the variability of Algol, as well as the duration of the brightness dimming.

Before the findings of the Jetsu and Porceddu team, historians of science attributed the discovery of Algol's variability to Italian astronomer Geminiano Montanari in 1667. English astronomer John Goodricke calculated the period of its variability 115 years later, something the ancient Egyptians had accomplished more than 3000 years earlier.

Cultures in the ancient past, from Egypt to Australia, developed complex systems of knowledge about the changing brightness of stars. In Australia, that knowledge is still thriving through living Aboriginal cultural practices. It is also something that can, and does, inform astrophysical research. And I am happy to report that the astronomical community is taking this seriously and is now including collaborations with Elders and programs on Indigenous Knowledges in research and education programs.

This is where we will find true innovation.

CHAPTER 8

The Cataclysmic Stars

‘One night Janowaree appeared as a bright new twinkling star on the edge of a black space in the Milky Way. The people shouted and rejoiced as they believed this was Janowaree escaping the clutches of the evil spirit-man to become his own star.’

—Traditional Aboriginal story from southern Queensland

On the coast of Arnhem Land in Australia’s Northern Territory, Yolŋu people maintain an oral tradition about two brothers, *Nuruguya-mirri* (the elder) and *Napiranbiru* (the younger), who were fishing out at sea when a storm rushed in suddenly. The brothers frantically paddled towards the shore, but the crushing waves capsized their bark canoe. Napiranbiru, who was not as strong a swimmer as his older brother, began to struggle. Nuruguya-mirri helped his younger sibling reach land but drowned in the process. People rushed to the shore when they saw the damaged boat on the sand. They soon found Napiranbiru, who told them of his brother’s heroic deed. After the storm subsided, Nuruguya-mirri’s lifeless body washed up on the beach.

The community held a ceremony to honour the elder brother’s heroism and sacrifice. That night, ‘a bright star shining, new and sparkling’ appeared in the sky. The people believed it was Nuruguya-mirri letting them know he was now with the ancestors. The younger Napiranbiru lived a long life, growing to old age. Before he passed, he asked the spirits to place him in the sky with his brother. The siblings are now visible as two bright stars close together on the bank of the sky river, *Milnguya* (Milky Way). They are accompanied by a small campfire, represented by a faint red star nearby.

In Aboriginal cultures, traditional Law rewards acts of selflessness, which are celebrated and immortalised in oral tradition. Interestingly, this narrative illuminates an element of observational astronomy: the appearance of a bright new star in the sky. It could simply be a symbolic description, but these sorts of things *do* appear in the sky on rare occasions—one exactly at a specific

place in the sky the story says. In the world of astrophysics, not all variable stars are slow pulsators. Some explode in spectacular fashion, appearing in the sky as bright new stars for weeks or even years before fading to invisibility … and a select few return.

Astrophysicists research these events to learn about the lives and deaths of stars, and cosmologists use them to study the expansion of the Universe. In astrophysics, the appearance of a 'new star' in the night sky is called a *nova*. Novas (and their closely related cousins, *supernovas*) signify either the death of a star, or a curious imbalance in a pair of stars—both of which lead to a violent end.

Most of the stars in the sky are systems of two or more stars, all orbiting each other in a complex gravitational dynamic. Novas form in binary systems, where a white-dwarf star is closely orbited by another star. The white dwarf has a strong gravitational field that draws matter from its companion. As the dwarf does this, it increases in mass until it reaches a critical limit, resulting in a thermonuclear explosion. This event can be seen from across the galaxy as a bright 'new' star, before fading from visibility, which can take days to months.

Novas occur as frequently as ten per year, but those rivalling the brighter stars in our sky are only visible a couple of times per century. The brightest nova of the past four centuries appeared in the constellation Aquila in June 1918. The nova, known as V603 Aquilae, achieved a peak brightness of –0.5 magnitude (to be outshone only by Canopus and Sirius), but rapidly dimmed over the next two weeks, eventually fading below the threshold of visibility. It is now so faint you need a telescope to see it.

The death of massive stars and some types of white dwarfs can produce a supernova. These give off a lot more energy than novas and can outshine an entire galaxy before fading away weeks or months later (or, in some cases, years). They occur less frequently than novas, but if one happens in our region of the galaxy, they can outshine the brightest stars. Those that rival the brighter stars are only visible every couple of hundred years. The brightest supernova visible in recorded history appeared in the constellation Lupus in the year 1006. With a peak magnitude of –7.5, it was nearly twenty times brighter than Venus. More than four centuries have passed since the last bright supernova graced our night skies in 1604.

The fishermen brothers

In the Yolŋu tradition of the two brothers, the siblings are now seen as two stars close together on the bank of Milnguya, the sky river (Milky Way), the two stars that represent the stinger of Scorpius in Greek mythology: Shaula and Lesath (Lambda Scorpii and Upsilon Scorpii, with magnitudes of 1.6 and 2.7, respectively). Shaula and Lesath are culturally significant stars not only for Yolŋu people but for Aboriginal people across Australia.

In a version of this story from Blue Mud Bay in eastern Arnhem Land, the elder brother collapsed on a rock and died from exhaustion after saving his younger sibling. This version makes no mention of a new star in the sky and says the brothers, their catch of fish and their canoe are seen as 'starless spaces' in the Milky Way. The younger brother is represented by a dark nebula in the Milky Way, within the Western constellation Serpens. His older brother is a dark nebula near Sagittarius, and the rock on which the elder brother collapsed is seen as a portion of the Milky Way near the star Theta Serpens. Their capsized canoe is represented by a line of four small stars near Antares.

These nebulas lie within the 'galactic bulge'—the centre of the Milky Way galaxy as seen from Earth. This narrative clearly plays out within the galactic bulge, as traditional artworks depicting it show the brothers and their canoe in this exact region of the sky. Aboriginal people in Arnhem Land use Scorpius to indicate when the trade winds are changing and the wet monsoon season is approaching. Yolŋu people continue to observe when the stars of Scorpius dive into the sea (set at dusk) around the start of December, when the monsoon rains begin. The weather at this time can quickly change from pleasant to dangerous so they need to be alert for signs warning them about seasonal changes that affect conditions at sea.

Yolŋu people watch for signs of storms at sea by making connections between the celestial brothers and weather. The brothers serve as spirit guardians, warning fishers about storms and the danger of fishing far out at sea during this time of year. Aboriginal people fishing at sea look for the first signs of an approaching storm, long before the sound of thunder or strong winds. When storms brew, the star-brothers leave their celestial abode and come down to Earth to fish from their bark canoe. Yolŋu fishers keep an eye out for the brothers, who appear as shadows on the water or soft light in the evening sky. When fishers see the early warning signs of a storm they head to shore, saying that the brothers are warning them.

Ancient cultures around the world, such as those in China, Korea, Arabia,

Rome and India, kept written records of star positions and astronomical phenomena. Modern historians of astronomy look to these records for important information about celestial events, such as the dates novas and supernovas occurred, where in the sky they were visible and how long they were seen. In using these records, we make a startling realisation.

Chinese scholar Shen Yue recorded in the *Book of Song* (*Sòng Shū*) the appearance of a bright guest star in *Wěi*, a bowl-shaped asterism (a pattern of stars that is not a constellation) comprising the stars in the tail of Scorpius, including the stars Shaula and Lesath. It appeared in the second lunar month (between 27 February and 28 March) of the eighteenth year of the Taiyuan reign period (393 CE) and disappeared during the ninth lunar month (between 22 October and 19 November). The star appeared in a dark patch in Wěi that denotes a dark nebula in the centre of the asterism.

Calculations show the guest star reached a peak magnitude of −1, appearing as the second brightest star in the sky after Sirius for eight months before then fading from visibility. It was just 4 degrees from Shaula and Lesath, and very close to the dark nebulas described in the Blue Mud Bay traditions. The *Barra' Mirri Mayaltha* (north-west monsoon season) occurs during the months of February and March and is dominated by heavy trade winds and sea conditions that can turn from calm to severe rather quickly.

The description in Chinese records prompted astrophysicists to search the sky for a remnant of the guest star. Originally thought to be a bright nova, astronomers dismissed the idea as the candidates known to them did not fit the Chinese descriptions of its brightness and duration of visibility. A supernova was a better fit. In 1996, astronomers used data from an all-sky survey conducted by the ROSAT X-ray space telescope to identify the supernova remnant (with the catalogue name RX J1713.7-3946) as the best fit for the guest star. Further studies conducted in 2002 confirmed this.

The proposed 393 supernova ('SN 393' using the standard naming practice) is a remarkable candidate for the older brother's spirit in the stars. But is this the only one? On 11 March 1437, Korean royal astronomers recorded the appearance of a bright new star in the constellation Scorpius. Just like SN 393, the star appeared in the asterism *Wěi*, between the stars Zeta and Eta Scorpii. But unlike SN 393, it faded from view just fourteen days after it appeared. Modern astrophysicists realised that the Korean astronomers recorded a *nova*, not a supernova. In 2017, astrophysicists led by Michael Shara at the American Museum of Natural History in New York identified

the remnant of Nova Scorpii AD 1437, matching it perfectly to the Korean records and finally solving the mystery.

Nova Sco 1437, as it is known, appeared just a few degrees away from where SN 393 was seen more than a thousand years earlier. It *could* be the 'new star' observed by the Yolŋu people. The Yolŋu people would have seen SN 393 low in the south-eastern sky around 11 pm when it reached peak brightness. Curiously, Nova Sco 1437 also appeared in March, so it would have been visible in the same direction about the same time of night as SN 393, a full millennium before. It is worth noting that this part of the sky is the middle of our galaxy. Visible supernovas are more common here, so it is unclear which (if any) of the possibilities are described in oral tradition. But it would be a remarkable coincidence if a bright new star did indeed appear in this part of the sky, clearly visible from that part of the world, at the time of year that correlates to events described in the story.

If the Yolŋu tradition does describe the elder brother appearing as a supernova (bright new star), why are the siblings now identified as the stars Shaula and Lesath? All novas and supernovas fade over time to invisibility. SN 393 faded over the course of eight months, never to be seen again. If Nuruguya-mirri's appearance in the sky was a supernova, then the Yolŋu people would have needed to choose suitable stars to fit the story after the star faded away. In this case, it might seem suitable to choose a close pair of bright, prominent stars to represent the brothers. Of the stellar pair, Shaula is brighter, representing the seniority and prominence of the older brother, Nuruguya-mirri.

The height of the monsoon season occurs from February to March. If the appearance of a bright new star was describing SN 393, then this pair of conspicuous stars were selected to align with the narrative and the appearance of the older brother in the sky, acting as seasonal markers and serving as a mnemonic device for celebrating selfless acts of heroism and maintaining Law.

Janowaree and the spirit-man

The Yolŋu story of the two brothers is not the only Aboriginal oral tradition that describes the appearance of a bright new star in the sky. A story from southern Queensland tells of a young boy named Janowaree who was an excellent hunter. He was chasing a brush turkey in the bush with his friends

when the bird transformed into a man covered in red ochre and brandishing a *nulla nulla* (a short blunt club with a pointed tip). The man was an evil spirit-being who came down from the Milky Way to hunt for lost children.

The spirit-man grabbed Janowaree and they disappeared into the sky, never to be seen again. The other boys ran home and told their families what had happened. The people kept an eye on the Milky Way over the following nights, searching for a sign from the captured boy. One night, Janowaree appeared as a bright new twinkling *karoola* (star) on the edge of a black space in the Milky Way. Upon seeing this new star, the people shouted and rejoiced as they believed this was Janowaree escaping the clutches of the evil spirit-man to become his own star.

The ochre-covered spirit-man is probably the bright red star Antares, which is known by a number of other Aboriginal groups as a man covered in red ochre (like Nyeeruna or Waiyungari in the previous chapter). The story does not give the exact location of Janowaree in the sky, but the description of a bright new star appearing near a dark space in the Milky Way is much like the description of the Yolŋu brothers and is generally consistent with both SN 393 and Nova Sco 1437.

It could also refer to another guest star recorded by Chinese astronomers just seven years earlier in 386 CE in the constellation Sagittarius. This supernova appeared in the Milky Way near a dark nebula, reaching a magnitude of +1.5. Another possibility is the brightest supernova in recorded history, SN 1006, which reached a peak magnitude of −7.5, substantially brighter than Venus. It was visible in the constellation Lupus at the edge of the Milky Way and was so bright it could be seen during the day. Similarly, SN 1604A appeared in the Milky Way near a dark nebula in the constellation Ophiuchus, reaching a peak magnitude of −3.

Regardless of which of these candidates it may have been, the appearance of a bright new star in the sky is not a concept born purely from imagination. It is a phenomenon that would have had a significant impact on people who carefully observed the stars and the cultures that gave traditional names and meanings to each one. A bright new temporary addition to the celestial canvas would have been a clearly noticeable and meaningful sight, and there are several examples of this in the bright novas and supernovas that have appeared unexpectedly in the sky over the centuries.

Based on data from the last two millennia, bright supernovas (those exceeding a magnitude of −1) appear with a frequency of about four per

millennia. Extrapolating backwards in time, we can consider that more than 260 bright supernovas have been visible in the skies over the minimum time Aboriginal people have been in Australia: 65,000 years. The examples we have examined are promising, but inconclusive. With so many of these stellar explosions visible in our skies over this time, and with traditions of hundreds of cultures that have survived, do any contain a clear-cut observation of a cataclysmic star?

The great eruption of Eta Carinae

Not all bright ‘new stars’ are novas or supernovas. Some cataclysmic variables act as ‘supernova impostors’, appearing in the sky as a bright new star before fading. But unlike supernovas, the eruption does not destroy the structure of the star. These strange objects can go through multiple eruptions, appearing to get brighter before fading numerous times throughout the star’s lifespan. The study of a star like this led a pair of astronomers to a realisation so significant it made global headlines.

In the constellation Carina lies a system of two blue-giant stars. One star has the mass of 80 Suns and the other equals well over 100. The larger is also extremely unstable. The pair are collectively known as Eta Carinae, and the total light they give off is the same as 5 *million* Suns. The larger of the pair occasionally puffs up and sheds its outer layers, increasing in temperature and brightness in the process. The increase in brightness can last for several years. Given its size, luminosity and distance, this shedding event can make it appear as one of the brightest stars in the sky. And that is exactly what happened back in the mid-nineteenth century.

Visible for centuries as an inconspicuous star, Eta Carinae began to brighten significantly as it shed its outer layers in the 1830s, ejecting twenty times the mass of our Sun into space. In 1837, it surpassed the brightness of Rigel, marking the start of an event known as the Great Eruption. By March 1843, Eta Carinae had increased in magnitude to become brighter than Canopus, rivalling Sirius as the brightest star in the sky for a few weeks.

During the Great Eruption, the gas belched out into space began to cool, solidifying into dark dust grains that blocked out the stars’ light. Eta Carinae appeared ruddy in colour; then it began to slowly fade away. By 1856 it dipped below the threshold of visibility, remaining hidden from view until 1892 when it made a brief appearance before fading to invisibility yet again.

Since 1940 it has gradually brightened to once again become a run-of-the-mill fourth-magnitude star in the plane of the Milky Way.

In 1847, a few years after Eta Carinae's brightness peaked, Englishman William Edward Stanbridge took up a pastoral licence at Tyrell Downs, near Lake Tyrell in the Mallee region of north-western Victoria. Stanbridge developed a keen interest in Aboriginal culture and befriended the local Boorong people, a clan of the Wergaia language group. The Boorong prided themselves on knowing more about astronomy than any other Aboriginal group and taught Stanbridge some of their star knowledge. Years later, Stanbridge wrote about how he had sat with two unnamed Aboriginal people by a campfire on a large plain by the lake where they shared some of their star knowledge with him. Unfortunately, he did not record their names, but we will hereafter refer to them as the 'Boorong astronomers'.

Stanbridge presented a paper on Boorong astronomy to the Philosophical Institute of Victoria on 30 September 1857. His paper was published the following year in the journal *Transactions of the Philosophical Institute of Victoria.* In the paper, Stanbridge discussed 40 astronomical objects and phenomena, as well as information about Boorong seasons. While learning about Boorong star knowledge from the two Aboriginal astronomers, he translated the traditional names to English and used a star atlas to identify the stars' Western counterparts.

The Boorong astronomers described several stars as animals and characters in the narratives of oral tradition, showing their interrelated links and associations. They spoke of Bunya, the ring-tailed possum, as the red star Gamma Crucis, who was chased to the top of a tree (the Southern Cross) by Tchingal, the human-eating emu in the Milky Way. They spoke of *Warepil*, the eagle, represented by Sirius, and his brother, *War*, the crow, represented by the star Canopus. Stanbridge appeared to have little trouble identifying most of the stars pointed out to him by the Boorong astronomers.

But one star stood out, and it seemed Stanbridge had difficulty identifying it. After writing about War, the crow (pronounced *wah*), and talking about his relationship to other stars in the sky, Stanbridge recorded *Collowgullouric War* as a female crow, the wife of War. She was described as a 'large red star in Rober Carol, marked 966. All the small stars around her are her children.' Rober Carol is a reference to *Robur Carolnium*, Latin for 'Charles' Oak', which is a now-defunct constellation invented by the famous astronomer Edmond Halley (of Halley's Comet fame) in 1679 that was prominent in the

star catalogues of the day. It was appropriated by Halley from the larger and also defunct constellation Argo Navis.

The old constellation of Robur Carol comprises stars in the modern constellations of Centaurus, Vela and Carina. This region of the sky is within the plane of the Milky Way and is densely populated with fainter stars. These are the ‘small children’ surrounding the crow-wife. The number ‘966’ is a reference to the Carinae Nebula, in which the Great Eruption of Eta Carinae appeared. Since the catalogue was made before the Great Eruption, Stanbridge’s chart would not have shown a bright star in that part of the sky. This explains why he wrote down the description of what he saw along with a catalogue number.

The Boorong astronomers were describing a truly remarkable astronomical event. The description of the star’s brightness, colour, location and catalogue number is a clear reference to Eta Carinae during its Great Eruption. Stanbridge happened to record the star knowledge of the Boorong firsthand during the period the star was erupting, and it is evident that he did not realise this. Not only did the Boorong people observe this rare transient event, but they also incorporated it into their pre-existing oral traditions as Collowgullouric War.

The Boorong people developed some themes in their star knowledge. Some of the stars have spouses accompanying them in the sky. Those with a single spouse are represented by stars of comparable brightness located in the same general region of the sky. If a star has two wives or husbands, this spousal-pair are of similar brightness to each other and are either brighter or fainter than the main spouse. The trio of stars also forms a roughly linear pattern in the sky.

As examples, the pair of eagles is represented by the bright stars Sirius and Rigel. *Kourtchin* are two brolgas (cranes); the male is the larger and the female the smaller of the two Magellanic Clouds. Djuit is the red-giant star Antares and his wives are Tau Scorpii and Sigma Scorpii, two fainter stars of similar brightness to each other that flank him (as discussed in Chapter 7: The Variable Stars).

Why was Eta Carinae identified as the wife of War (Canopus)? Prior to its Great Eruption, Eta Carinae was an inconspicuous fourth-magnitude star in a part of the sky densely populated by stars of comparable brightness. It would not have stood out, nor would it have fit the theme of stellar spouses found in Boorong astronomy. Did War even have a celestial wife prior to the 1830s?

The nearest bright star not otherwise discussed in Boorong traditions is Beta Carinae, the second brightest star in Carinae. But at magnitude 1.65, it is not an ideal candidate for War's wife as Canopus is significantly brighter.

We do not know the answer to that question. But we do know that Eta Carinae has gone through other eruptive events in the past; astrophysicists have observed larger shells of debris surrounding the unstable star that indicate this. Perhaps there are other accounts of the Great Eruption, or earlier outbursts, of Eta Carinae in astronomical records or traditions.

A mystery from Samoa

Is the crow-wife a recurring figure in the Boorong night sky that spends most of her time hidden among the stars, making an appearance only on rare occasions? Or did she first appear in Boorong astronomical traditions in the nineteenth century to explain the Great Eruption of Eta Carinae? These questions remain unanswered, but the Boorong record of the Great Eruption of Eta Carinae remains the first and only confirmed Indigenous record of this event anywhere in the world.

Or is it?

Curiously, a paper on Samoan astronomy includes a paragraph that describes something intriguing. The author, John Stair, said that on 13 May 1840 several Samoan locals told him they saw

> that morning in the north, a little before sunrise, a strange phenomenon—a bright red star that had the extraordinary appearance of being closely encircled by a number of other stars of ordinary appearance. This strange phenomenon was observed at Falelatai, on the south coast of Upolu, Samoa, by persons in whom I had every confidence.

Stair's account did not provide any more detail, but it did provide a few important pieces of information: the location from which the observation was made (Samoa), the direction of the star (north), a general description (bright, encircled by other smaller stars), the date (13 May 1840), the time of day (morning) and the star's colour (red). The description is strikingly similar to the account recorded by Stanbridge, and it was right at the time that Eta Carinae began rapidly increasing in brightness.

This might seem like a clear-cut account of that eruptive star, but aspects of the description do not match. For example, Eta Carinae is seen in the *south*, not the north. And it would have been visible in the *evening* in May,

not in the morning. There was no indication that the red star had been incorporated into Samoan oral traditions or previously known to the people but given how little of Samoan star knowledge was recorded or documented, this is not exactly meaningful or conclusive. Why the inconsistencies if it was Eta Carinae?

The article was published nearly 60 years after the event occurred. Was information lost or distorted by a fading memory or inaccurate records, or did some of the details just get mixed up? The variable star Mira was below the limit of visibility at the time, and except for Eta Carinae no other known novas or supernovas were visible in any part of the sky. Given the nature of the description, it would be a remarkable coincidence if the people described seeing an event known to have occurred at that time, and for it *not* to be a reference to Eta Carinae. More likely, this is an error on the part of Stair's memory or notes.

We may never know for sure, but future studies may reveal the answer.

Pueblo rock art

One of the most famous claims of supernovas recorded in ancient traditions comes in the form of a crescent Moon and star motif on paintings and a rock-art design in Chaco Canyon, New Mexico. This is the land of the Ancestral Pueblo and is a topic of extreme public interest, refuted claims and a hook for tourism. The story of the supposed supernova rock art is one of twists, unsubstantiated claims, heated scholarly debates and a hunt for the truth.

On 4 July 1054 CE, a bright new star appeared in the constellation Taurus —so bright, it could be seen clearly during the day and was the third brightest object in the sky after the Sun and Moon. Japanese, Chinese and Indian astronomers recorded its appearance, and references to it have since been found in records from the Middle East. Japanese astronomers noted its appearance more than two weeks earlier than the Chinese, describing it as being as bright as Jupiter, but growing more luminous each day. Chinese astronomer Yang Weide recorded the guest star (*kè xīng*) in 'the first year of the Zhihe era, seventh lunar month, 22nd day' during the Song dynasty (960–1279). 'Zhihe' refers to the reign of Emperor Renzong, which occurred between 1054 and 1056. Weide wrote that the guest star 'appeared at dawn, in the direction of the east, under the watch of Tiānguān [the star Zeta Tauri] seen in daylight, like Venus. It had rays stemming in all directions, and its

colour was reddish white.’

It was visible in the daytime sky for nearly a month and was seen at night for the better part of two years before gradually fading from view. As with any unexpected transient phenomena, the sudden appearance of a guest star served as an omen to many ancient peoples, who linked them to wars, pandemics or political upheavals. Nestorian Christian doctor Ibn Butlan, working in Baghdad, linked the appearance of the 1054 guest star to disease epidemics in the Near East:

> One of the famous epidemics of our time has occurred when a spectacular star appeared in the year 446 [of the Muslim calendar]. In the autumn of that year, fourteen thousand people were buried in Constantinople. Thereafter, in the middle of the summer of 447, the majority of the people of Fostat and all foreigners died. While this spectacular star appeared it caused the epidemic in Fostat by the Nile being low when it appeared.

The story of the guest star of 1054, recorded nearly a millennium ago, remained little more than a footnote over the centuries, but became a centre of scientific attention hundreds of years later. In 1758, astronomers were eagerly scouring the skies for the anticipated return of Halley’s Comet. A French astronomer, Charles Messier, was searching for the first signs of the approaching comet, which was predicted to be visible in the constellation Taurus. Its exact location was uncertain, and Messier had some difficulty finding this celestial needle in the haystack of fuzzy patches filling the night sky. Observing one of these patches, which resembled the still-faint comet, he soon realised that it was not moving from night to night like a comet but remained stationary.

This patch was a nebula discovered by English astronomer John Bevis in 1731, but Messier was not aware of this discovery three decades earlier. Messier realised the importance of cataloguing all non-cometary fuzzy patches in the sky, including various types of nebulas, star clusters and distant galaxies. Nebulas are clouds of gas and dust, and their different forms represent stellar nurseries or the icy graves of stars that have met a formidable death. When the 1054 guest star exploded as a supernova, its outer layers were blown violently into space. This cloud of debris expanded, forming a large shell of gas and dust, known today as the Crab Nebula.

Messier recorded this first object to prevent further confusion in the night sky. He went on to compile a list of 110 similar objects, several of which he is credited with discovering. The cataloguing system, which is still used by astronomers today, refers to objects by their Messier number. The Crab

Nebula is known as Messier 1 or M1. By comparison, the Pleiades are dubbed M45. So where did the name ‘Crab Nebula’ come from? In 1840, Anglo-Irish astronomer William Parsons, the 3rd Earl of Rosse, observed the nebula through a 36-inch telescope and made a drawing of what he saw. His illustration looked a bit like a crab, hence the name. Other nebulas named after their appearance include the Witches Head, Dumbbell, Cat’s Eye, Soap Bubble, Lemon Slice, Footprint, Soccer Ball, Stingray, Spare Tyre, Butterfly and Eye of Sauron nebulas. Yes, really!

A few years after Parsons’ drawing, at the same time that Eta Carinae peaked in brilliance during its Great Eruption, French astronomer Jean-Baptiste Biot and his son, engineer and sinologist Édouard Biot, studied the *Wenxian Tongkao* (‘Comprehensive Examination of Literature’), a 348-volume Chinese encyclopaedia that was compiled during the Yuan dynasty in 1317 by Chinese historical writer Ma Duanlin. The Biots were the first to attempt to analyse ancient Chinese documents of novas and comets but had still not made the connection between the Crab Nebula and the guest star of 1054.

American astronomer Carl Otto Lampland was using telescopes at Lowell Observatory in Flagstaff, Arizona, in 1921 when he compared photographic plates and noticed changes in the structure of the Crab Nebula. At the time, it was not known how the nebula had formed, and this became the subject of much debate. A comparison with photographs of the nebula from twelve years earlier showed that it had clearly grown: the nebula was expanding. In the 1920s, this was a highly unexpected result. The scientific establishment thought the Milky Way was the entire Universe. Watching a nebula expand over such a short timescale was a scientific curiosity that was soon to contribute to a new view of the Universe in Western science.

Also in 1921, the same year that Lampland first realised the Crab Nebula was expanding, Swedish astronomer Knut Lundmark was busy compiling records of guest stars from Chinese star catalogues. He noted that the description of one of these was close to the Crab Nebula but did not take the extra step and draw any clear connection between the two. Seven years later, the famous astronomer Edwin Hubble (for whom the Hubble Space Telescope is named, and, like me, a Missourian) completed his doctoral studies on nebulas at Mount Wilson Observatory in southern California. He continued his work, photographing the Crab Nebula and comparing his plates with earlier photographs. This proved conclusively that the nebula was still

expanding, and he suggested it was formed by an exploding star.

Based on the observed expansion rate, Hubble calculated that the Crab Nebula had formed about 900 years earlier. Comparing this information with the historical Chinese records compiled by Lundmark, Hubble realised there was only one explanation: the Crab Nebula was the expanding shell of debris caused by the guest star of 1054. The Crab Nebula was the right kind of object, in the right place in the sky, dating to the era the 1054 guest star appeared, which was described by Japanese, Chinese, Indian, Arabic and perhaps even European astronomers.

Although Hubble made the connection between the expanding nebula and the guest star of 1054, it would still be several years before the idea became more widely known. Astromoners Fritz Zwicky and Walter Baade published a paper in 1933 showing that these types of novas formed by a unique process and become extremely bright for much longer durations of time than traditional novas. This led to the scientific understanding of what we now call supernovas. A year later, astronomer Nicholas Mayall suggested that the 1054 guest star was one of these supernovas, rather than a traditional nova. His main argument was that novas are visible for only weeks to months. The 1054 guest star had been visible for nearly two years.

Mayall joined forces with Dutch astronomer Jan Oort and sinologist J.J.L. Duyvendak in 1942 to look more closely at ancient records of guest stars and link them to the expanding nebula. Their work concluded that the Crab Nebula is almost certainly the remnant of SN 1054. In the 1960s, astronomers identified a spinning neutron star at the heart of the Crab Nebula. Neutron stars are the breathtakingly dense cores of stars that go supernova, further strengthening the case.

This helps us understand how the guest star of 1054 and the Crab Nebula are related. But it was the claim that ancient Native American motifs represented this transient celestial event that eventually led to a tsunami of public interest. In 1955, Mount Wilson Observatory astrophotographer William Miller published a paper suggesting that two Native American paintings represent SN 1054 next to a crescent Moon. Miller’s reasoning, admittedly circumstantial, was that the design represented what the supernova would have looked like in the sky on 4 July 1054 when it first appeared: a bright ‘new star’ a few degrees away from the crescent New Moon.

The lack of motifs of a similar design, Miller argued, points to this being a rare event. Shards of pottery in the area were dated to around the same period

the supernova was visible, and a range of other ideas were presented to drive the point home. The idea was a slow burn for nearly twenty years before it finally took off. In 1973, a team of researchers published a paper expanding on Miller's idea. This kicked off decades of speculation, debates, documentaries, and an expedition to the desert to locate the rock art and test the claim once and for all.

In the years that followed, cracks in Miller's hypothesis began to appear. His claim that iconography of this nature was extremely rare in Native American rock art was flipped on its head when several examples were identified in sites across the American south-west, including California, Nevada, Utah, Arizona, New Mexico, Texas and the Baja region of Mexico. Anthropologists argued that the conflicting and highly circumstantial nature of Miller's hypothesis highlighted the caution astronomers need to exercise when making claims of this nature. Did this discourage astronomers? No, in fact it seemed only to embolden some of them. The additional motifs of a similar design, which are found across the south-west, were touted by astronomers as even *more* examples of SN 1054 recorded in rock art.

In Chaco Canyon, New Mexico, a rock overhang features a group of motifs showing a crescent, a 'star', a handprint and what looks like a comet (at least that is a popular interpretation). This was promoted as further evidence of Pueblo representations of SN 1054, and some suggested the 'comet' motif represents the passing of Halley's Comet in 1066, which appeared twelve years after SN 1054. This is arguably one of the most popular rock-art paintings in the world related to astronomy. A series of papers arguing for the connection between these motifs and SN 1054 were published over the following years. One famous paper, which outlined the arguments supporting the connection in detail, was hailed as solid proof, but the very next paper in the edited volume completely refuted the idea. As it turned out, these motifs are not uncommon. They are well known. From the Torres Strait to the Muslim world, the combined crescent and star motifs depict the crescent Moon and Venus when the two objects are visible near each other.

Dr Edwin Krupp is an astronomer and the director of Los Angeles' iconic Griffith Observatory, overlooking Hollywood. He has maintained a longstanding interest in archaeoastronomy, especially claims about supernovas in rock art. For three decades he has been visiting these sites to identify and analyse every example of traditional art supposedly linked to SN

1054. He realised that no researcher in the last half century had ever been to the sites described by Miller. He set out to do just this, but it proved to be an arduous challenge. Queries led to dead ends and the rock-art experts he contacted were not even aware of the sites in question.

Miller's descriptions of their locations were vague. Krupp finally managed to contact two researchers at the Museum of Northern Arizona, who found documentation about the sites deep in the museum's archives. Excited by the breakthrough, the trio set off to find them. After obtaining permits to access the Navajo Reservation, they realised the difficulty they faced in reaching the sites. After hours and hours of off-road driving, long hikes and hairy near misses in the remote desert, they finally found one of them. What they saw was surprising.

The artwork looked relatively bright and fresh, indicating that it was recent. The other rock art nearby was faded and clearly much older. These motifs did not seem like they had been ceremonially repainted, and the artwork certainly did not look in the slightest like it was 900 years old. In fact, it did not even look like a crescent and a star! Rather, it more closely resembled the head of a *Wupá'ala*, a long-horned *kachina* spirit in Hopi traditions.

Rock art in Chaco Canyon, New Mexico, which some claimed represents Supernova 1054. (Michael Lloyd, Wild Light Imaging Studio)

The idea that this represented a historical supernova seemed odd and unlikely. At the other site, the supposed supernova artwork was actually a smaller component of a complex panel of designs representing an array of animals and geometric patterns. It was not easily distinguishable from the others. Krupp realised that Miller's photos of the artwork were quite misleading. He came to the conclusion that the whole idea—no matter how popular and exciting—was bunk.

This raises an important question: did the Ancestral Pueblo people observe the supernova and include it in their rock art? It would be nearly impossible that the Ancestral Pueblo did *not* see it. SN 1054 was the third brightest object in the sky at its peak and could be plainly seen during the day for

nearly a month; it was visible at night for almost two years. Of course they observed it, and there is no reason to believe they did not incorporate this into their traditions or perhaps depict it in artistic motifs.

We simply do not know if the motifs identified by some researchers are representations of SN 1054. It seems more like the imposed views of Western astronomers, or at least their fanciful ideas. From spoke-shaped rock art to circle motifs, some scholars are quick to link icon designs to supernovas with no evidence whatsoever.

One of the most famous examples of this comes from self-proclaimed archaeologist George Michanowsky. In 1977, he published the book *The Once and Future Star* in which he proposed that the Vela supernova, now estimated to have formed between 11,000 and 12,000 years ago, was witnessed by ancient people of Bolivia and recorded in their rock art. The rock face in question features four small circles, flanked by two larger circles. Michanowsky argued that the four smaller circles represent the stars of the asterism of the False Cross, which lies on the border of the constellations Carina and Vela. The two larger circles supposedly represent the star Canopus and the Vela supernova.

Aside from the lack of any supporting evidence for this interpretation, Michanowsky goes further by claiming that this part of the sky—specifically the region of the Gum Nebula—was known to contemporary First Peoples of the region as *Lakha Manta*, meaning ‘Gateway to Hell’. The people rejected that claim, saying that they have no knowledge of the petroglyph’s meaning. They also rejected Michanowsky’s claims, saying the rock art has no connection to their astronomical traditions. Michanowsky went on to link ambiguous iconography on Mesopotamian clay tablets with the Vela supernova, with similarly inconclusive results.

I spent a decade living in Sydney’s northern suburbs, near Lane Cove National Park. Within the park is a rock platform containing Aboriginal motifs carved into sandstone, surrounded by more recent carvings made by European settlers in the 1800s. The Aboriginal motifs show a crescent and a star-like ‘sunburst’ design, as the park authorities described it. Without any context (and it seems none is recorded), one could claim that the rock art depicts SN 1054, as it looks much like the designs in Chaco Canyon. If it were depicting a celestial event, it is far more likely to be a crescent Moon and Venus, which are commonly represented in Aboriginal traditions across Australia. The reality is that without knowledge from the Traditional

Custodians, it is difficult to know, and making unsubstantiated claims is simply poor scholarship.

Informing modern astrophysics

The teachings of Elders, as well as new perspectives on old historical records, show that Indigenous Knowledge is constantly changing ideas and challenging claims in the history and philosophy of science. This knowledge is also informing practices in modern astrophysics. Indigenous descriptions of new stars appearing in the sky can guide astronomers as to where they should point their telescopes and can provide details about the object's brightness and appearance that we can only estimate today. Alternatively, astronomers searching for the faint shells of dead stars might discover the remnant of a supernova that was visible as a bright star in the sky a few thousand years ago, which may be recorded in oral tradition.

Dr Natasha Hurley-Walker, an astrophysicist at Curtin University in Perth, led a project to observe our galaxy using low-frequency radio telescopes in the Western Australian outback. Her research led to the discovery of 27 previously unknown supernova remnants. One of them, dubbed G0.1-9.7, was found in a relatively empty region of the galaxy, in the constellation Sagittarius. Calculations suggest it is young, perhaps appearing in the sky just 1200 years ago, around 820 CE.

This does not correspond to any known historical supernova, even though observant, record-keeping cultures would have seen it, had it appeared. In any scientific observation, uncertainties in measurements lead to margins of error. Calculating how fast the supernova nebula is expanding, or determining its distance away from us, is no easy task, and uncertainties in these estimates can give a large window of time in which the stellar explosion could have been visible from Earth. While an age of 820 CE is the lower limit of the supernova, the upper limit is about 9000 years.

The question Dr Hurley-Walker posed is simple: do any oral traditions from cultures in the southern hemisphere describe the appearance of a bright new star in that part of the sky? This is a great question and a prime example of how Indigenous star knowledge can guide astrophysical research. Where should astronomers point their telescopes? What did the 'new star' look like and how long was it visible? These questions can be guided by Elders. Astrophysicists and Elders working together to learn more about our

Universe is an exciting prospect. This approach is one the astronomical community is now taking on board and actively developing.

CHAPTER 9

The Navigational Stars

‘Each night where we were going to travel back to the camp. How to travel? Follow the star along … we didn’t have a watch in those days. We always followed the star for the watch.’

—Yidumduma Bill Harney, Senior Wardaman Elder

Using the stars to navigate by land and sea requires knowledge of positional astronomy and mathematics. There are many ways one can navigate using the stars, including the Sun, and the complexity of this knowledge is significant. The techniques and tools that are used range widely. Navigation, like so many things, is a holistic process. It includes knowledge of animal behaviour, wind and ocean currents, cloud types and movements, trade winds, and variations in atmospheric temperature and pressure, among other factors. We have already touched on some of these topics in this book.

Celestial navigation is often cited as an example of the great advances in human innovation, enabling people to spread across the globe, crossing great distances by land and sea tens of thousands of years ago. Pacific Islanders are an excellent example of this approach. The Pacific Islanders’ traditional systems of science and knowledge about the stars, for instance, enabled them to navigate sea-voyaging craft across the vast Pacific. From the islands of Hawaii to Rapa Nui/Easter Island and Aotearoa/New Zealand—the Polynesian Triangle, as it is often called—encompasses an area of 2 million square kilometres.

To give some idea of scale, this is roughly equivalent to visiting islands that stretch from Edinburgh in Scotland to Zanzibar off the eastern coast of Africa, to Hong Kong. Additionally, evidence proves that Polynesians reached South America, and Māori people inhabited subantarctic islands. Traditional accounts of Māori mariners, such as *Ui-te-rangiora* in the seventh century, describe reaching the far southern edge of the sea at a place called *Tai-ukaa-pia* (‘sea foaming like arrowroot’). This, combined with other

evidence, suggests Māori navigators spotted the coast of Antarctica before the claimed European ‘discovery’ of the continent in 1820.

Indigenous navigators are held in extremely high regard in their communities. Their role is critical, and their craft is complex and skilled. The techniques of navigation and wayfinding are taught through oral tradition. Navigation students are required to learn and memorise through mnemonic devices the names, positions and relative angles of all the bright stars and constellations in the sky when observed at dusk and dawn throughout the year, and how they relate to specific islands.

These are taught through star maps, which include knowledge of ocean currents, trade winds, animal behaviour (particularly birds), the Sun, Moon and other factors that require careful observation. Students learn these interconnected links through various teaching aids. In the Marshall Islands of Micronesia in the western Pacific, these aids include *mattang* (stick charts), which use bent sticks, shells and fibre to represent ocean currents and swells relative to each island. Teachers sometimes educate students about star charts using shells, stones and connected fibres. None of these were carried on voyaging craft, but rather served as teaching aids and mnemonic devices.

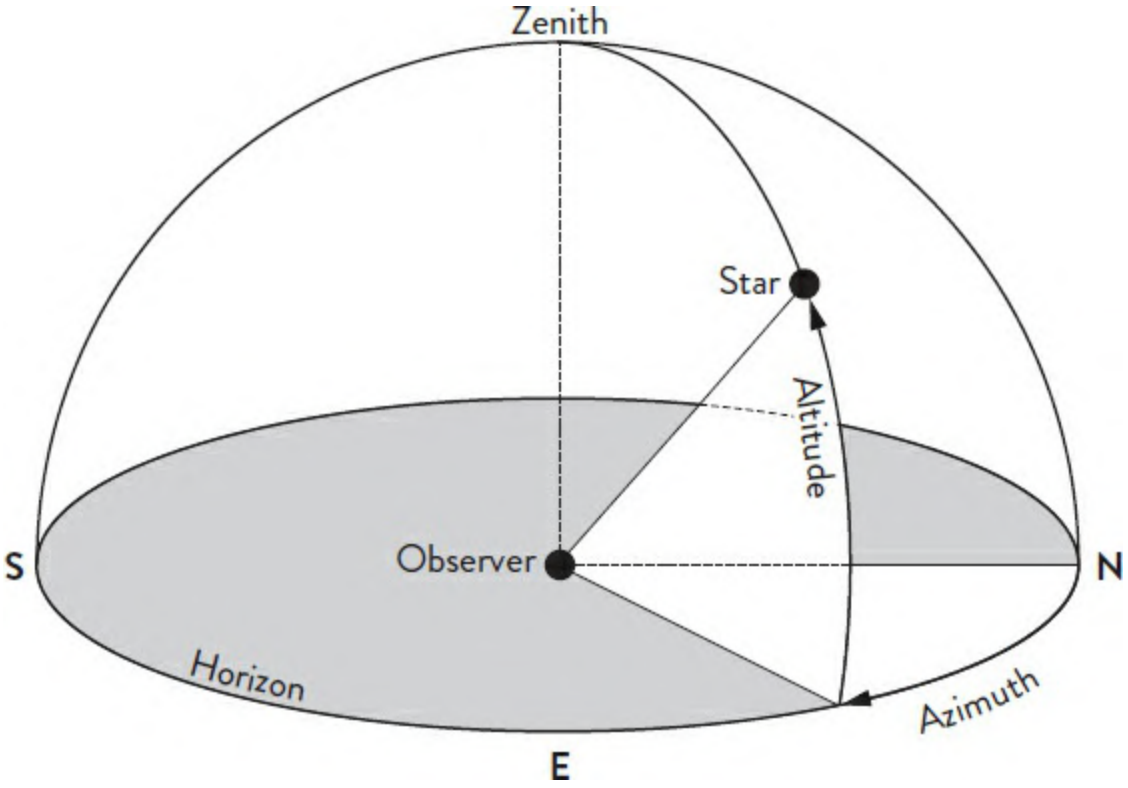
Coordinate systems

To understand how stars can guide travellers and serve as waypoints on a journey, we use coordinate systems to identify our position, and the position of our destination on a sphere. For celestial navigation, two general types of coordinate systems are used: azimuthal and equatorial. Different cultures will have their own names and conceptions of these systems, but they generally work in very similar ways.

The *azimuthal coordinate system* defines the position of a star based on the observer’s location, treating the sky above as a dome. The two main directions are the azimuth and altitude. The *azimuth* is the circle along the horizon, and *altitude* is the circle traced out from the horizon to the point directly above us (*zenith*) to the point directly below us (*nadir*). The circle of azimuth consists of 360 degrees (as all circles do). It starts at due north (0 degrees) and moves clockwise to due east (90 degrees), due south (180 degrees), due west (270 degrees), around to due north (360/0 degrees).

Altitude is a circle measured above or below the horizon. An object’s altitude at the horizon is 0 degrees, which increases upwards into the sky

until you reach zenith at 90 degrees or decreasing downward from the horizon until you reach nadir at −90 degrees. The imaginary line across the sky connecting north and south is called the meridian. When objects cross the meridian, they reach their highest altitude in the sky (with the exception of circumpolar stars—stars that circle the poles and never reach the horizon). Since stars are fixed on the celestial dome, they each rise and set at a given azimuth (or bearing), making them reliable indicators of direction for navigators. As their altitude increases, they become more difficult to use for direction.



How an observer views azimuth and altitude on the celestial dome

However, the movement of the stars across the sky requires a different coordinate system, which is based on the rotation of the Earth. Earth-based geographic coordinates, such as latitude and longitude, as well as the equator and poles, are projected onto the celestial sphere. The projection of Earth's equator into space is the *celestial equator*, which runs from east to west. The angle of the celestial equator in the sky will depend on the observer's latitude

on Earth, which crosses directly overhead at the equator and lies along the horizon at the North or South Pole. The celestial equator is tilted from the ecliptic (the path of the Sun) by 23.5 degrees, which is the axial tilt of the Earth. Where these two circles meet defines the equinox points.

The projection of the Earth's poles onto the celestial dome are called the *celestial poles*, around which all the stars rotate. If you are looking to the south celestial pole (SCP), the stars appear to rotate clockwise in the sky. If you are looking to the north celestial pole (NCP), they rotate anticlockwise. In the northern hemisphere, Polaris is the closest star to the NCP, lying less than 1 degree away. This is a convenient navigational star as it is bright, with a magnitude of 1.98 (being among the 50 brightest stars in the sky). In the southern hemisphere, the closest star to the SCP is Sigma Octantis. However, with a magnitude of only 5.47, it is extremely faint, and thus not a very reliable pole star. Therefore, other techniques are used to find South, which we will discuss later.

The projection of the Earth's latitude onto the celestial sphere is called *declination*, and the projection of longitude is called *right ascension*. Declination defines the lines running parallel to the celestial equator. Just like the latitude on Earth, declination represents circles that go from east to west and measures the positions of stars either side of the celestial equator. The circles of declination differ in size; the largest circle is at the equator and the circles decrease in size until they become stationary points at the celestial poles. Since declination measures angles of objects from the celestial equator to the celestial poles, it is described in terms of degrees, arcminutes and arcseconds.

Just like lines of longitude, lines of right ascension measure the angle around the Earth from north pole to south pole. Similarly, the lines of right ascension converge at the celestial poles. Unlike circles of declination, the circles of right ascension are all the same size, as they run from north to south. The circles of right ascension denote time. On Earth, lines of longitude are reflected in time zones, although they are often bent and twisted around countries due to convenience and politics. In space, these lines denote where a star will be at a given time of the year. As such, right ascension is measured not in degrees, but in hours, minutes and seconds.

Any star that passes over zenith lies on the celestial equator, rising at due east and setting at due west. In Kiribati, an archipelago of islands along the equator in the central Pacific, navigators note the positions of stars, such as

the Pleiades and Antares, relative to their declination north or south of Rigel. From an equatorial latitude, the stars of Orion lie along the celestial equator, moving in this way. The end star of Orion's belt, Delta Orionis, lies almost right on the celestial equator, with Rigel and Betelgeuse about 8 degrees either side. The Pleiades and Antares are both about 25 degrees either side. Understanding the relative positions of these stars is critical for determining the directions of other islands, which lie at certain azimuths relative to each other. Each island serves as a waypoint on a longer journey across the Pacific.

From equatorial latitudes, all the stars rise and set along the horizon. But for observers at higher or lower latitudes, some stars never reach the horizon —they are always in the sky, day or night. These stars are deemed circumpolar. For observers at the North and South Poles, all the stars are circumpolar. It is worth noting that due to the Earth being a globe, the azimuth of any given star varies slightly, depending on an observer's latitude.

One critically important observation and measurement involves the altitude of the celestial pole. Since the equatorial coordinates are a projection of the Earth's geographic coordinate system, the altitude of the celestial pole is equal to the latitude of the observer. If you are in Hawaii and *Hokupa'a* (the star Polaris) is 20 degrees above the horizon, you know you are at a latitude of 20 degrees. This is the Big Island.

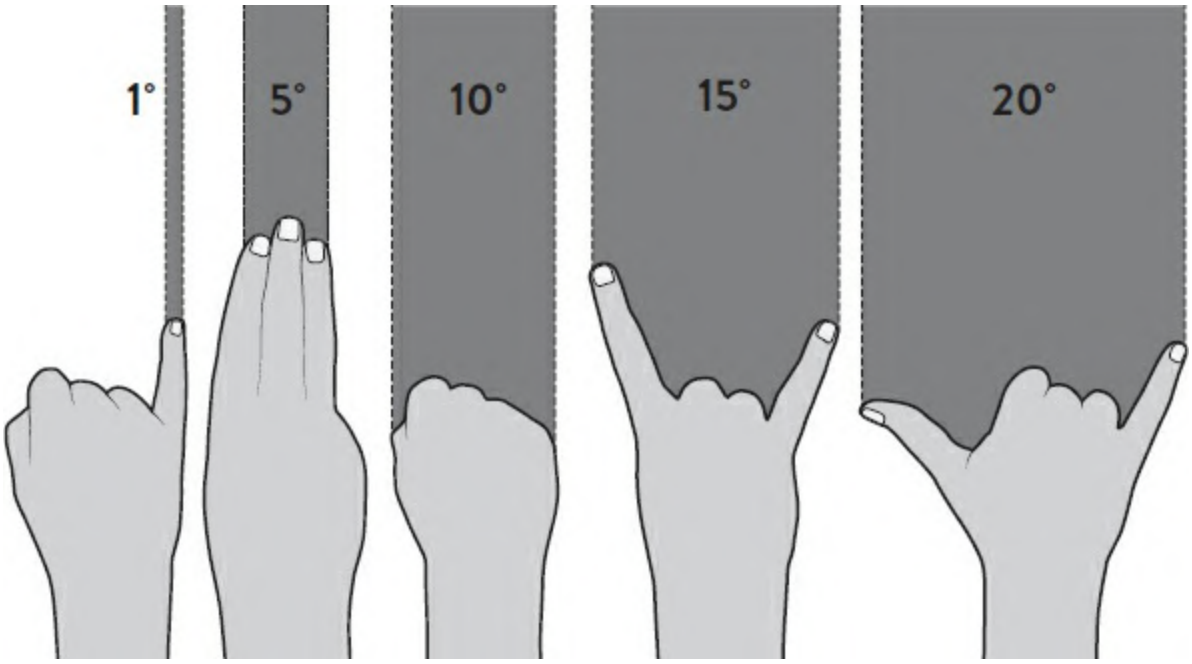
How is this measured?

Tools for navigation

Over the millennia, navigators have developed different tools for measuring and remembering star positions. Before the astrolabe, kamal, octant, sextant or GPS, a common tool used by First Peoples across the world, from the Inuit of the Arctic to the Polynesians of the South Pacific, was the hand. Hands and fingers have long been used to measure distances between stars and the horizon, as well as between the stars themselves, and they are still used today. Methods of using the hand are surprisingly complex, but a simplified version involves measuring angles from 1 degree to 20 degrees. To try this, place your hand at full arm's length and extend your little finger. The width of the little finger at the last joint is about 1 degree of arc. For comparison, the Sun and Moon are each about half a degree of arc. They may seem big in the sky, but when you hold out your little finger for comparison, you realise

how small they actually appear.

Place your index, middle and ring finger together: their width at arm's length is about 5 degrees. A fist is 10 degrees, and your index and little fingers extended outwards ('heavy-metal horns') is 15 degrees. The thumb and little finger extended ('surfer sign') is about 20 degrees. These are only approximations, and since each person has a unique anatomy, each person must figure out the values their hands measure. For example, the 'surfer sign' is 20 degrees for some people, but 25 degrees for others.



Using the hand to measure degrees of arc

Navigators need to be able to measure degrees of arc with reasonable accuracy, as 1 degree of arc equals about 60 nautical miles (a bit over 110 kilometres). This involves using a range of features on the hand, including joints, knuckles, folds in the skin, fingertips and hand width. To measure the altitudes of stars, navigators place their thumb on the horizon and measure the angular distance of the star above this point. This is famously illustrated in the Disney animated film *Moana*. In the film, you can see the title character measure the altitude of the belt stars in Orion with her hand. Around 2000 years ago, the period in which the film is set, the most easterly

of the three belt stars of Orion was positioned at due east when it reached an altitude of about 20 degrees. The altitude of stars in the Southern Cross are used to measure latitude. When the Cross is positioned upright, the altitude of the bottom star, Alpha Crucis (which is also the brightest in the constellation), can be used to estimate the observer's latitude. We will discuss how this works a little later.

To make sense of how the hands can be used to measure angles and degrees of arc, it is first essential to know the relative positions of all the bright stars, when they rise and set, and their relative azimuth on the horizon. This is taught to navigator students, who must memorise upwards of 150 stars. The azimuth of each star is memorised, as well as its home quadrant and the time of year it rises and sets, the cardinal directions, the relative positions of the Sun at solstice and equinox, as well as the wind and ocean current directions and the movements of birds.

Navigators also observe the width and colours of the Sun's path on the water. The path is narrowest when the Sun is at a low altitude and increases in width as it reaches higher into the sky. You need to know what the sky looks like from your starting point, and it helps to know this from your destination. This complex and comprehensive body of knowledge is used by master navigators to traverse thousands of kilometres of open sea.

The art of celestial navigation faced such a decline in the era of rampant colonisation that navigators were becoming incredibly rare. In 1976, the Micronesian Master Navigator, Mau Piailug, led a Hōkūleʻa (double-hulled canoe) voyage across the Pacific using only traditional seacraft and traditional navigation techniques and tools to retrace the route from Tahiti to Hawaii. The success of the Hōkūleʻa voyage proved the efficacy of these techniques, which have been used in the decades since to circumnavigate the globe.

These routes are taught through complex star charts, which require a reference point. As Nainoa Thompson, president of the Polynesian Voyaging Society, explains:

> You cannot look up at the stars and tell where you are. You only know where you are in this kind of navigation by memorising where you sailed from. That means constant observation. You have to constantly remember your speed, your direction and time. You don't have a speedometer. You don't have a compass. You don't have a watch. It all has to be done in your head. It is easy—in principle—but it's hard to do. The memorisation process is very difficult.

Thompson is a Hawaiian *Pwo* (navigator) who trained as a student of Mau

Piailug. Pwo are highly regarded, having been initiated in the art of traditional navigation and wayfinding as practised in the Caroline Islands archipelago of Micronesia. To learn more, readers are directed to the 1996 film *Spirits of the Voyage* and the 2013 book *Hawaiki Rising* by Sam Low.

The complexity of celestial navigation shows that First Peoples have long been aware that the Earth is round, not flat—an idea also shared with ancient and medieval Europeans. The local environment appears flat and is often described as such—even in the Western discipline of positional astronomy. But on a larger scale, people have long known that navigating long distances only makes sense if the Earth is round. Observers travelling long distances from south to north will recognise the shifting positions of stars in the sky. For example, if you travel from Darwin to Adelaide, you will notice stars that once set below the horizon are now circumpolar and no longer set at all, like the Southern Cross. You will notice that stars you could see in the northern skies of Darwin no longer appear in the sky from Adelaide at all. You will also recognise that the south celestial pole ascends higher in the sky as you travel further south. The opposite happens if you travel northward. The same situation applies in the northern hemisphere, only with the directions reversed.

In 1881, two young Noongar women from the south coast of Western Australia were in conversation with a white woman. The Noongar women were asked if the Earth was round like a ball or flat. They both responded that it is round, like a ball, and explained why:

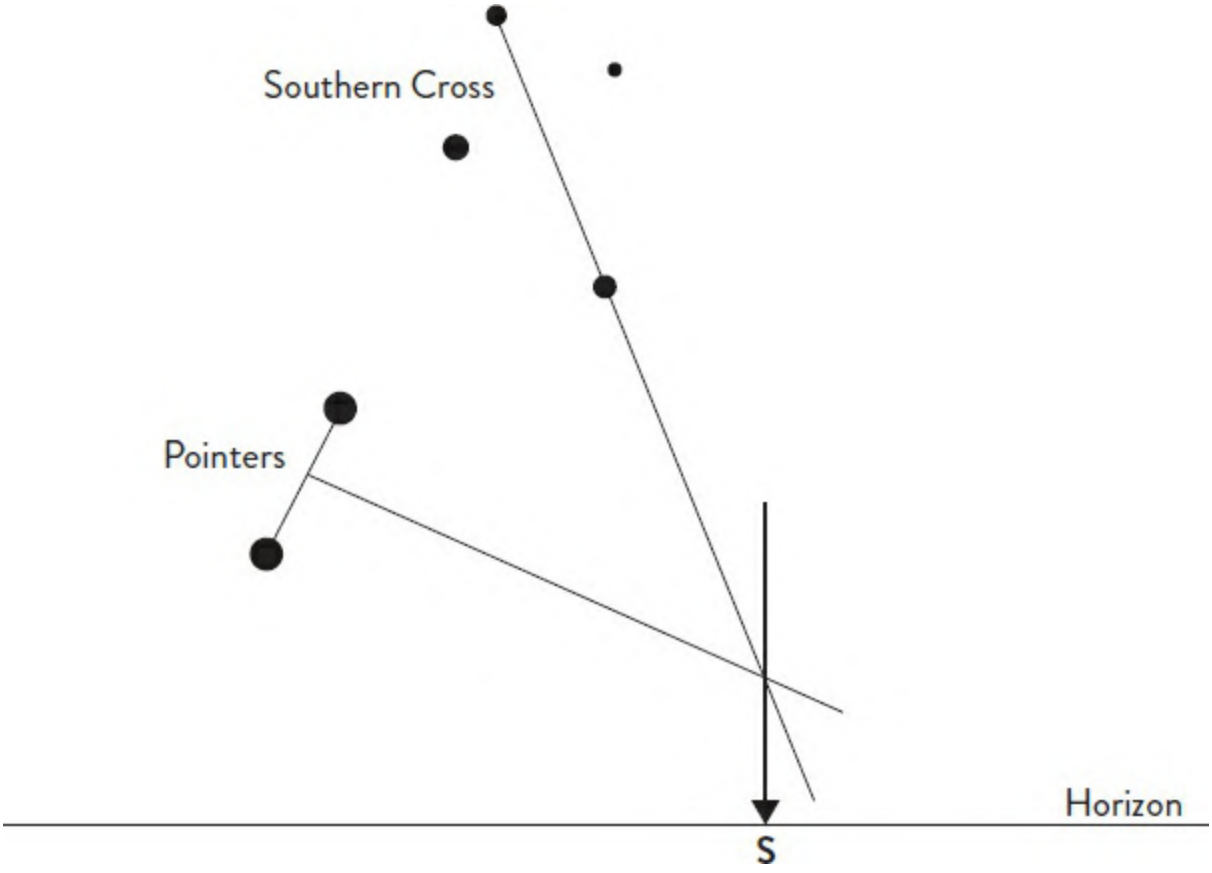
> Just look all around you—see the sky touching the earth all around. Wherever you stand and look it is all round. Put baby down to walk and he soon run around. Not always straight like along a fence. When ships get lost they run round. When white man get lost he go round and round.

This comment would later reflect a personal experience that highlights the truth of the Noongar women's statement. We'll get to that at the end of this chapter.

Finding south

The stars are used to locate the cardinal points. In the southern hemisphere, the Southern Cross is commonly used by Aboriginal and Torres Strait Islander people to find south. Meriam Elders Ron Day and Meddy Kaigey

both explained that sailors travelling from Erub to Mer will steer their canoe towards the left hand of Tagai (Southern Cross), since it rises over Mer as seen from Erub. Wardaman Elder Yidumduma Bill Harney says, ‘That Emu Foot [Southern Cross] tells you he’s south. If you want to go south-west, you go on the right-hand side of the emu.’



Using the Southern Cross and Pointers to find south

Navigators commonly use a technique to find south that triangulates the position of the south celestial pole (SCP) using Southern Cross and the Pointer stars (Alpha and Beta Centauri). Draw an imaginary line between the Gamma and Alpha Crucis and extend that downward, then find the midpoint between the Pointer stars and draw an imaginary line with your hand perpendicular to them down in the sky. Where the two lines intersect is the SCP. Well, it’s close enough. The SCP is about 2.5 degrees away. From that point in the sky, simply move your hand straight down to the horizon and that

is the direction of south.

A second technique is to measure the distance between Alpha and Gamma Crucis with your hand, then measure four times that extending down. That is the same point—just over 2 degrees from the SCP. Alternatively, the star Achernar has a declination of about −57 degrees, the same as Gamma Crucis (Gacrux). Imagine a spot between the Pointers and Southern Cross, but at the same declination as Gacrux. The SCP is halfway between that point and Achernar. There are several different methods one could use, and First Peoples used some of these in their own ways to determine south.

As we learned with Polaris, the altitude of the celestial pole is the latitude of the observer. If you can use your hands and fingers to measure the altitude of the SCP above the horizon, you will know your latitude. Go outside tonight and try it yourself, either with Polaris for the northerners, or Southern Cross for the southerners. If you see them both on the horizon, you know you are on the equator.

Changing techniques

Each community uses its own technique for finding directions with the stars, and this often depends on latitude. First Peoples might use a range of techniques with Southern Cross to find south, but it is important to mention that these techniques evolve over time. Elders always teach that Law is set, but knowledge systems themselves are dynamic and changing. The world around us changes, so the systems of knowledge that explain and make sense of it—especially those elements that use the world around us to predict future events such as seasonal change—must also change. Due to the slow wobble of the Earth and the fact that the stars orbit the centre of our galaxy, the positions of stars slowly change over time. It may seem like a slow process, but it does not take very long for them to move enough to make some of these techniques moot.

Aboriginal people have been living on the land we now call Australia for tens of thousands of years. And we know that navigation has played an important role in the hundreds of cultures across the continent. But the Southern Cross technique itself is not nearly that old. For example, a mere 1000 years ago, it would not have worked well at all. Due to precession, the point in the sky we define as a celestial pole constantly changes, albeit slowly.

Right now, Polaris is about 1 degree away from the NCP. Go back or forward in time by a millennium, and that will change. A thousand years ago, Polaris was 6 degrees away. Four thousand years ago, it was 22 degrees away. As we can see, Polaris will not be a fitting name in the distant future, as it will not be anywhere near the pole. The same process applies with the Southern Cross and the Pointers. If we go back a thousand years, the intersection of the lines through Southern Cross and the Pointers would have been 13 degrees from the SCP. Go back 2000 years and that distance is nearly double.

The other technique, of using four times the distance between Gamma and Alpha Crucis in a straight line, also would not have worked. Two millennia ago, the distance of Southern Cross from the SCP was over seven times that value. Because it was nearly twice as far from the SCP 2000 years ago as it is today, its use as a nightly clock would also have been different, as Southern Cross would not have rotated at the same rate back then.

Navigational constellations

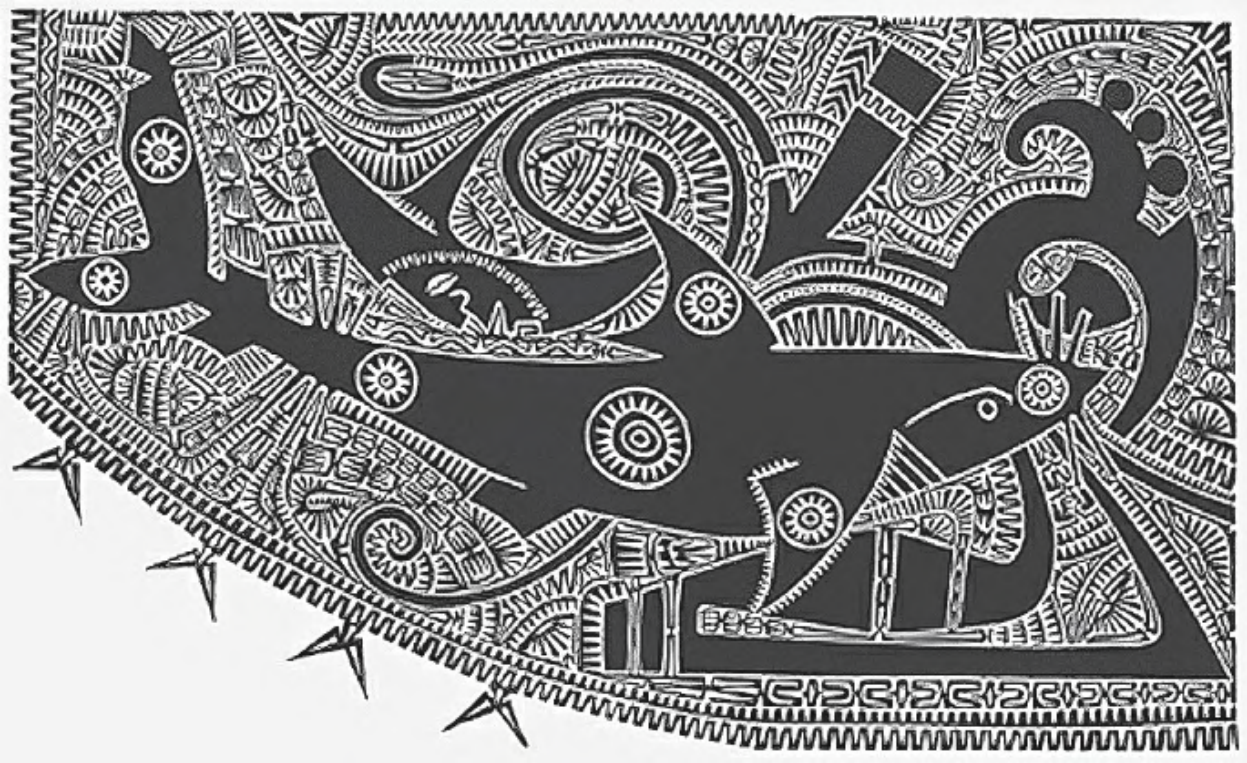
As well as individual stars, larger constellations are also utilised for navigation. They serve a dual purpose: marking direction and tracking time. These constellations vary in size and meaning, but you will notice they tend to be conspicuous and linear. They need to have a clear orientation. Uncle Yidumduma explains how Aboriginal drovers would watch the stars of Scorpius to navigate land at night. Not only would they follow the direction of the constellation, but as it rotated throughout the night, it served as hands on an analog clock, with the changing position corresponding to changing times.

In Gunditjmara Country of western Victoria, an Elder named Kuyuut, his daughter, Tarneen, and her husband, Tuulawarn, recounted the oral tradition of *Banukill*, a ‘great hunter of kangaroo rats’ (bettongs, a rat-like marsupial). The narrative features several stars in the Western constellation Hydra. In a book published in 1881, pastoralist James Dawson noted how the long linear constellation ‘guided the people in their night journeys, enabling them to judge the time of the night and the course to be taken in travelling’.

The constellation known colloquially as the Big Dipper is used by navigators in the northern hemisphere. The two stars at the end of the Dipper, Merak and Dubhe, point to Polaris. As the constellation rotates throughout

the night, its orientation in the sky serves as a timepiece. In the Torres Strait, the stars of the Big Dipper appear upside down compared to how they are viewed by northern-hemisphere observers, as this latitude is south of the equator. The constellation represents Beizam (the shark) in Meriam traditions.

Beizam's position throughout the year after dusk indicates seasonal change and guides the behaviour of sharks. Islanders use it as a navigational aid as it sits low in the northern sky. The gills of the shark point towards north, which are the two stars at the far edge of the Dipper (Merak and Dubhe). This Meriam constellation has such significance that in early 2021 it was the focus of a commemorative coin released by the Royal Australian Mint. Uncle Segar Passi's artwork is featured, showing the nose of the shark touching the horizon at dusk, when lightning flashes signal the approaching monsoon rains. The coin sold out within two hours, one of the fastest sellers in the mint's history.



***Baidam Thithuyil,* by Brian Robinson (2010) (Baidam means 'shark' in Kala Lagaw Ya, and Thithuyil refers to a constellation of stars). (Courtesy of Brian Robinson and NorthSite Contemporary Arts)**

The Southern Cross was, and still is, used as a timepiece as well as a navigational aid. We learned in Chapter 6: The Seasonal Stars how the Mursi people of Africa use the constellation as an analog clock over several weeks to time pulsations in the flooding of the Omo River. The constellation can also be used over the course of a night in a similar way. By observing the orientation of Southern Cross at dusk, one can observe its clockwise rotation to estimate time. It rotates at the rate of about 1 degree every four minutes, or about 15 degrees per hour. Southern Cross will move approximately 90 degrees every six hours.

Sometimes non-stellar objects and phenomena are used as navigational tools. In the community of Ulguniq (Wainwright, Alaska), Iñupiat people observe the aurora borealis to note direction. They noticed long ago that when the aurora is visible as long bands, it stretches from east to west. The lights are typically observed around midnight to orientate themselves. This orientation follows the auroral zone, a ring that encircles our planet at latitudes near the Arctic and Antarctic circles, stretching from east to west.

The plane of the Milky Way is used to predict ocean currents in the Torres Strait that aid sea voyaging. The section of the galaxy between Southern Cross and Sagittarius—the same as the Aboriginal celestial emu—is seen as Kaigasul Usul, the shovel-nose ray (of the genus *Rhinobatos*). The ray, called Kaigas, scours the sea floor in search of food. As it does this, it kicks up silt and debris from the floor of the reef. This creates a dirty cloud of silt, which is called *usul*.

Uncle Alo Tapim is an educated linguist. He explained to me that the suffix *-ul* at the end of Kaigas denotes its celestial counterpart. Kaigasul Usul is the view of the Milky Way with the cloudy ‘dust’ kicked up by the ray as it scours the waterway in the sky. In the Meriam Mir language, the Milky Way is called *pi* (pronounced ‘pee’), meaning ‘dust’. Boigu Islanders observe Kaigasul Usul as a seasonal indicator. They know the galaxy runs north-east to south-west. When the head of the shark ‘looks’ towards the east, the people know the ocean currents will be running to the west. When the head points to the south and the tail to the north, the current will be running to the east.

Star maps and Songlines

Not all stellar navigation is about following stars at night. Another novel

technique uses the stars as waypoints on a journey across the land. Long-distance travel routes are mapped out in the stars, which are then committed to memory. This method reflects the idea discussed earlier that nearly every Elder around the world teaches: everything on the land is reflected in the sky.

These travel routes are used for trade, attending ceremonies and a whole assortment of other purposes. As travellers make their way along their journey, they 'sing' the land, which encodes important information and commits it to memory, such as the location of prominent land features, waterholes, food sources and more. These are often called Songlines or song series. As Uncle Ghillar Michael Anderson has said, 'To every story belongs a song. To every story belongs a dance. To every story belongs a person. To every story belongs a place. And they all connect when we go through the ceremonies.' These Songlines can extend for hundreds of kilometres, and many are based on the stars. One of the most famous is The Seven Sisters Songline, which stretches across the central half of the country. The songs can change language as travellers journey onto new Country. A great deal has been written about this, and curious readers are directed to the 2020 book *Songlines: The power and promise* by Margo Neale and Lynne Kelly.

Once a travel route is determined, this information is committed to memory through star maps. The stars that are selected best represent the locations of important places, with the imaginary lines between them indicating pathways across the land to those places. In this manner, stars become waypoints on the journey. Once groups of stars are selected for this purpose a narrative is developed that connects them together, and this can be reflected in song. Elders then teach younger generations about these star maps at night. Later in the year, when it is time to travel, the people go by day, having memorised the waypoints and pathways using the star maps.

In 2017, Noongar Elder Dr Noel Nannup appeared on *Stargazing Live*, a major televised event about astronomy and space. He joined astronomer Greg Quicke and explained how five bright stars trace out a large W-shape in the sky, which forms a large star map. They mirror the Songlines on the land, and are committed to memory. This star map starts at Aldebaran, then goes to Betelgeuse, Rigel, Sirius, and finishes at Canopus. The orientation of the start and end stars—Aldebaran and Canopus—runs north to south.

Each of these stars represents a place on the land, a turning point in the journey marked by a prominent large granite rock. These waypoints mark out a pathway that extends some 700 kilometres across Western Australia. The

locations represented by the stars are the Stirling Ranges (Aldebaran), Narrogin (Betelgeuse), Wave Rock (Rigel), near Merredin (Sirius), and Lake Moore (Canopus). Wave Rock is an impressive geological structure that is featured in Aboriginal star traditions of the region, serving as a place from which an ancestor being stepped into the cosmos to form the Milky Way.

Across the continent in Goodooga, New South Wales, Uncle Ghillar sat with Bob Fuller at night and pointed out groups of stars that are used to teach Euahlayi people how to travel to Quilpie, Carnarvon Gorge and the Bunya Mountains for ceremonies and trade during the summer months. Bob realised these stars were not in the direction of the travel routes. The stars in question are visible towards the south, while the travel routes are to the north. In fact, the stars in the map are not even visible during the summer months.

In traditional fashion, Uncle Ghillar left Bob with a few clues to piece together by himself as part of his educational journey. Bob realised the stars represent waypoints on the land and the pathways between those stars are the travel routes across the land. When he worked it out, Bob approached the Elder about his idea. Uncle Ghillar responded, 'Yes, you got it!'

The star maps and Songlines taught by Uncle Ghillar represent travel routes to destinations hundreds of kilometres away. Quilpie, Carnarvon Gorge and the Bunya Mountains are all in Queensland and are each about 600 kilometres from Goodooga. Back in Chapter 4: The Wandering Stars we read about the ceremony held near Quilpie in the section about planetary conjunctions. This is where two stones are brought together, which represent Venus and Mars.

Carnarvon Gorge is where deeply sacred but secret ceremonies are held, while the Bunya Mountains are home to the prized nuts of the Bunya pine (*Araucaria bidwillii*). Bunya nuts are plentiful every three years and begin ripening in January. They are harvested at intervals between two and seven years apart, during which celebrated gatherings took place that would last for several months. Visitors to these gatherings travelled from places up to 700 kilometres away, such as Dubbo in New South Wales.

The stars Uncle Ghillar pointed out are in the Western constellations of Scorpius, Ara and Sagittarius. They were selected as they best represent the overall orientations of important waypoints along the journey, such as a bend in a river, a waterhole, a marked tree or a stone arrangement. The Songlines are taught to travellers in May, June and July when these constellations are rising high in the sky after dusk.

The star map used to teach the travel route to Carnarvon Gorge starts with Gamma Sagittarii (representing Goodooga) then proceeds onwards using the stars in Scorpius as the terrestrial waypoints. Each of them is located along a watercourse, such as the Bokhara River, Balonne River, Bungil Creek and Charley's Creek. It is important to note that the travel routes are only loosely similar to the positions of the stars in the sky, as the star maps serve as a teaching and memory aid, not a scaled 1:1 cartographic map.

Songlines to highways

These Songlines and travel routes have been in use for long periods of time as people crisscrossed the country. When the first waves of colonists spread across the land, they used many of these existing pathways. They also stopped and set up camp at the waterholes and other places of abundant resources. In some cases, Aboriginal guides led them along the same routes and set up camp at the same places represented by waypoint stars.

Over time, the waypoints on the land became camps, then colonial settlements, and eventually towns and cities. The pathways between then became roads and highways. What you can see today is that many of the towns and road networks in Queensland, as elsewhere, are reflections of the Aboriginal star maps.

Highway networks based on ancient Aboriginal star maps are not restricted to south-east Queensland. Dr Nannup said the same applies to the W-shaped star map he described in Western Australia. Other famous highways across Australia have similar origins. For example, the Great Western Highway from Sydney across the Blue Mountains to Lithgow is a traditional Songline. Many streets in inner Sydney are based on local Songlines and travel routes.

The conversion of Aboriginal travel routes to modern highway networks is not something that only happened in the early days of colonisation. Uncle Yidumduma recalls watching his grandfather lead Europeans along a travel route across the Northern Territory that is today known as the Victoria Highway, which stretches from Katherine in the Northern Territory to Kununurra, across the border in Western Australia. In his 1996 autobiographical book, *Born Under the Paperbark Tree*, Uncle Yidumduma explains:

> They call it the Victoria Highway now, but it was never the Victoria Highway at all—it was just the original Aboriginal walking trail right through Arnhem Land and Katherine Gorge and past

> Willeroo, right down to Western Australia. They used that walking trail to trade their boomerangs and spears and many different ochres and [hold] ceremonial meetings.

It is essential to recognise the proper origins of what seem to many as modern developments. Chances are, where you live and how you get from city to city is based on Indigenous travel routes. And you can still see them each night mapped out in the stars.

Solar navigation

Celestial navigation need not only focus on the stars visible at night. We can also use our closest star, the Sun. One novel technique was used by Norse navigators over a thousand years ago. On overcast days, Viking sailors in the far north Atlantic needed to figure out an accurate way to locate the Sun in the sky. Without this navigational aid, they could end up dead or, more importantly, lose face and reputation—something Vikings held in high regard. The thirteenth-century Icelandic saga *Hrafns saga Sveinbjarnarsonar* describes a device called a sunstone (*sólarsteinn* in Old Norse) that was used to solve the problem. The Icelandic allegorical story *Rauðúlfs þáttr* describes the sunstone as a mineral through which observers can look to find the Sun on a cloudy day.

A French team of scientists at the University of Rennes, led by Dr Guy Ropars, believe the sunstone to be made from a variety of calcite crystals endemic to Iceland. This is how it works: the Sun's light forms concentric rings of polarised light around it. The crystal depolarises the light, enabling observers to see rings around where the Sun is located when it is hidden behind thick cloud cover. The team realised that calcite crystals have a unique property called *birefringence*, which splits incoming light along two paths that form a double ring on the far end. The brightness of the two rings depends on the polarisation of sunlight. If the orientation of two crystals can be changed—say by rotating them side by side—you can find the point where they are equally bright. This enables the observer to locate the Sun and obtain accurate compass readings.

It's an intriguing idea, but no Viking-era sunstone has ever been found. The team decided to test the theory in practice. Using a piece of Iceland spar (calcite), they made a simple wooden device that beamed sunlight through a hole in the crystal and projected the double image onto a surface. They tested it on an overcast day. The sunstone they developed was able to locate the Sun

with high accuracy.

In 1669, Danish physician Erasmus Bartholin realised that calcite crystals produce a double image when objects are viewed. Although he is credited with discovering the phenomenon, knowledge of it may have gone back at least six centuries before, if not longer. The only physical evidence that this crystal may have been used as a navigational aid comes from the shipwreck of a sixteenth-century warship, found near Alderney in the Channel Islands between the United Kingdom and France. When re-examining the rubble of the wreck on the sea floor in 2013, excavators found a crystal of Iceland spar that may have been used as a sunstone. It was sitting near other navigational aids.

In Chapter 2: The Nearest Star, we learned how the Sun moves across the sky at different angles throughout the year, being higher in summer months and lower in winter months. You can use the shadow of the Sun when it is high in the sky to find the cardinal directions, a technique that has long been used by First Peoples of the world. Place a stone at the tip of a stick's shadow, wait 15 or 20 minutes until the shadow moves, and the line connecting the tips of the two shadows is east–west. This technique is easy to use and once saved my life, and that of a colleague.

In 2012, a meteorite conference was held in northern Queensland, bringing together scientists from around the world. A post-conference field trip involved visiting meteorite craters and important geological sites across Central Australia. I had recently finished my PhD when I was invited by colleague and fellow Judo practitioner Dr Craig O'Neill to assist on the trip … all expenses paid. Given that meteorite studies is my favourite topic of research (and the focus of the next and final chapter), I was thrilled to accept.

A few days into the trip, we drove out into the desert to visit the half-billion-year-old Kelly West crater, south-west of Tennant Creek. We parked the vehicles on a dirt road as close to the crater as possible, but it was still a 7-kilometre hike through the bush to get to the structure's exposed rim. Armed with a compass and map, Craig led the procession through the desert scrub. I stayed back to help any stragglers. The last person to head off was a retired European scientist in his seventies who understood little English and was wearing shorts and sandals in spinifex country. For those not familiar with this native plant, spinifex are bushes of long stiff blades of grass with razor-sharp points jutting from the ends. I grabbed a bottle of water and we set off into the desert, thinking the team was not far ahead.

How wrong I was.

In my rush to catch up, I had neglected to bring a compass, a map or a phone, despite Craig's warning not to forget! I marched forward with ill-deserved confidence but was never able to find the group. Over an hour passed and we had still not caught up. We were lost. The bush looked the same in all directions and we could not see or hear anyone. The Sun beat down, water was running low and my colleague's bleeding legs illustrated the perils of experiencing spinifex in shorts.

I felt a twinge of panic but remembered a technique Dharawal Elder Les Bursill had taught me. Only a year earlier, Uncle Les was leading me through dense scrub in the Royal National Park, south of Sydney, to visit rock art. I mentioned how easy it would be to get lost, and he replied that you can easily find the cardinal directions by measuring changes in the Sun's shadows, or by looking at your shadow and the time to get an idea of your orientation.

I noticed my colleague was wearing a watch. By sheer luck, it was exactly noon. That meant that the Sun had reached its highest point in the sky and my shadow was pointing due south. I remembered Craig telling us the dirt road on which we parked ran north–south. Therefore, if we walked east, with the Sun to our left and our shadow to our right, we should find the road. We set off yet again. After what seemed like an hour, we saw nothing but endless scrub and spinifex. With raw nerves, I climbed a small tree in hopes of seeing the road—or anything.

No luck.

Dirty, dishevelled and half-dehydrated, with sunscreen dripping down my face, I feared my mistake might cost us our lives. I jumped down, shrugged and kept walking. My colleague's expression morphed from one of hope to one of concern. My mind raced as I tried to think of another way we could navigate our way through the desert. 'I'm an astronomer, I should know this, right?!' I thought. With my attention focused on finding a solution, I walked onwards for about 20 metres when something suddenly appeared out of the desert scrub. It wasn't a snake, thankfully. It was the dirt road.

The tree I had climbed had been *just* short enough and *just* far away enough that I did not see the road through the scrub, despite it only being a stone's throw away. I began waving my arms in the air and pointing down. The expression on my colleague's face quickly changed from one of fear to one of excitement. He ran towards me, saw the road and we began jumping up and down, cheering, laughing and embracing. As it turned out, we were a

couple of kilometres south of the vehicles. We probably looked ridiculous, but to us it was an immeasurable relief.

In hindsight, we were damned lucky. You read about this sort of thing happening all the time in Australia, with the bodies of lost hikers found just metres away from trails. We had walked in a giant circle. Although we missed the crater altogether, we were alive because of what Uncle Les had taught me. Important lessons were learned. However, what took centrestage in my mind were the Noongar women from the 1880s talking about the white man walking round and round when he gets lost.

Touché.

CHAPTER 10

The Falling Stars

'When someone dies, you see a falling star or "Maier". You always hear a sound in that direction. They received his spirit and the drums go "boom". The falling star is part of that.'

—Uncle Ron Day, Meriam Elder

In 2012, I was invited to work as a consultant for a tourism company in the Top End of Australia. Owned and operated by Aboriginal people, many of the tours focused on taking visitors in boats across the billabongs to see crocodiles, wildlife and the beautiful country of the area. The company wanted to expand this to a night tour, focusing on Aboriginal and Western astronomy. I went up with my then partner, who was also an astrophysicist. We had both worked as tour guides at Sydney Observatory and gained a lot of experience sharing astronomy with the public.

We spent the week organising the program, then joined the guides on a boat on the last night to lead them through the process of giving a 'star show'. We discussed views of the sky, and the Aboriginal guides were excited and engaged, sharing a bit of their star knowledge as we discussed the Western science. As I positioned my laser-pointer to the Milky Way, two meteors flashed across the sky.

My inner child always jumps with excitement when I see a shooting star, especially two at the same time, which is not a common occurrence. Meteors are one of my favourite topics in astronomy and were the focus of several of my early academic papers. But I remained quiet, as I was aware of what this phenomenon means to Aboriginal people across much of the continent.

One of the guides pointed up. 'With our people, a shooting star means someone passed away.' Everyone stood quietly for a moment before the guide changed the subject and everyone started chatting again. We continued with the training, headed back and turned in for the night. The next morning, my partner and I were preparing for our final in-class session with the guides.

But come meeting time, no one was there. We waited for another twenty minutes, before walking over to the manager's office to ask him where everybody was.

Unaware of what happened the night before, he looked up from his desk: 'Oh, my apologies. Most of the guides left this morning to deal with Sorry Business. Two Elders passed away last night.'

Despite my hard-lined scientific views, the hair on the back of my neck stood straight up.

Meteor spirits

Across Aboriginal Australia, and much of the world, meteors commonly represent the souls of the departed transitioning to the afterlife. In some places, they symbolise the eyes of evil spirits that hunt for lost children. They go by many names across different languages—Papinjuwari, Thuwathu, Indada, Namorrorddo. They are spindly creatures with long, sharp claws searching for the souls of the sick or dying. Their role and meaning are too complex to summarise properly, of course, but themes emerge that focus on the various properties of shooting stars that have special significance. These include their brightness, colour, trajectory and sound.

In the traditions of the Kaurareg people of Muralag in the southwestern Torres Strait, bright meteors are called *titurie udzurra* and are considered *marki* (spirits) that are greatly feared. These spirits and their families must be treated with continuous respect, otherwise sickness and death may come. Their path across the sky points in the direction where that sickness or death will occur. This is not set in time; sickness or death may come soon or not for a long time. But if a bright one is seen, the mood changes significantly. It is a sign to always be respectful.

I sat down with Uncle Alo Tapim, and with some of this information in mind, I brought up the subject of shooting stars. He explained that bright shooting stars are called *Maier* (pronounced 'My Air') in Meriam Mir. They play an important role in life, death and the transition between worlds. He taught me that Maier represent the spirits of people who are sick or passing to the afterlife. These spirits possess powers, including the ability to cause sickness and death. They are also featured in important kab kar (traditional sacred dances).

In Meriam traditions, the spirit of a sick or dying person is taken to the top

of the tallest tree by a family member or ancestor spirit. The tree is set alight and the spirit shoots across the sky as a bright meteor guided to Beig, the land of the dead, by the ancestor-being Terer. Beig is a spiritual place near the island of Boigu in the far north-west of the Torres Strait where spirits of the sick are healed or souls of the deceased transition to the afterlife.

Terer was a man whose spirit, after dying, travelled to various islands across the Torres Strait before finishing at Beig. Terer's mother followed him during his journey to bring his spirit home to Mer, where she attempted to revive him. A spirit's time on Beig is one of ceremony and celebration, lasting three days honouring the passing person's life. After that time, the spirit returns home as a Maier.

Physical characteristics of the Maier tell a story about that person. They inform observers when the person dies, their role in the community, the size of their family and even where they live. These all relate to when the Maier is seen, its brightness, trajectory, colour, sound and fragmentation. The timing of the appearance of a Maier is open to some interpretation. It does not necessarily mark the moment of death, although several Elders described personal experiences of that happening. It may occur before someone passes, or even days or weeks afterwards.

The brightness of the Maier generally reflects the importance of that person, on a personal or communal level. This importance, as with the brightness, is relative. When I sat with John Barsa, he explained that a really bright Maier might represent a senior Elder or leader. It was noted that fainter meteors had no special significance in Meriam traditions. In Kaurareg traditions, fainter meteors incite a sense of mockery, as those spirits are regarded as novices that have not yet learned how to utilise their full powers.

Elders explain that Maier are associated with the colour red, symbolising fire. In the Meriam Mir language, fire is called *ûr*. Uncle Ron Day detailed how a reef between Erub and Mer islands is traditionally called Meiri Reef (pronounced 'Mary Reef ') and explained that he is able to see what appear to be flames on, or near, the reef. His parents described it as spirits preparing a Maier and they called it 'Maier Reef ' among themselves. The island of Erub is just visible on the northern horizon from Mer and is easier to see from Uncle Ron's north-facing house on the top of the island.

In the Meriam language, the similar sounding word *mair* also refers to red ochre that was traditionally used in a sacred spiritual ceremony to paint the bodies of the dead. In some Aboriginal cultures, meteors have different

meanings depending on their colour. In Lardil traditions of the Gulf of Carpentaria, meteors showing no discernible colour are considered a good sign, such as the birth of a baby. If the meteor shows colour, particularly red, it is considered a bad sign.

If the Maier appears to give off *uir-uir* (‘sparks’), it indicates the size of the person’s family. The more uir-uir that are seen, the larger that person’s family. Kaurareg traditions regard these sparks as meaning the spirit had lots of children. When the person’s spirit reaches home, you will hear a loud booming sound, which Meriam people call *dûm* (doom). Hearing the dûm of the Maier is something almost every Elder described experiencing in their life.

Many of the Elders shared personal experiences about their interactions with the Maier. While some Elders admitted to limited knowledge about certain star groups or astronomical phenomena, the Maier was one that all the Elders could speak about in great detail—in terms of knowledge about them as well as personal experience with them. John Barsa recounted a spiritual incident that remained with him for the rest of his life.

One evening he was sitting at home on Mer, watching the Moon. A cloud moved in front of it, followed by the appearance of a Maier. The Maier had the shape of a man, which raced across the sky towards a local creek. It then gave off a deafening dûm, shaking the whole island. Uncle John met his brother-in-law the next day, who lives on another part of Mer, and had seen a spirit climbing a tree that night while cleaning his catch of fish. He saw the same Maier, but for him it appeared to be racing towards nearby Dauar island. Both men later found out that a Saibai Elder passed away that night.

The path, or trajectory, of the Maier can mean many things. It may tell you that the person’s spirit is travelling to Beig, or it may signal that the spirit is coming home, with its path revealing the direction of their home. A Maier can also manifest if the family of the deceased person is not respected or looked after properly. In this case, the trajectory of the Maier will tell you where the offending people live.

For some Elders, the Maier is more than a bright meteor or fireball. It has deeper spiritual significance and power that can manifest in strange and unexpected ways. In 2016, I sat with Uncle Ron Day on his front patio. Uncle Ron is one of the fluent speakers of Meriam Mir and one of the Elders who possesses a great deal of traditional knowledge. He spoke to me at length about the Maier and about a personal experience he had with its spiritual

presence on the other side of the world.

> When I was the Chair of the local government council, I was requested to travel to Glasgow in Scotland to repatriate ancestral remains with my Deputy Chair, Mr Sari Tabo. We were led to a building and told to go inside. The room was empty except for a few boxes. I tried to contact them through the song 'Maier Ikok' [Ikok are songs a person sings with tears falling from their eyes]. The room filled with something like smoke. It was the spirits. When I finished, the smoke left the room and I said to Sari, 'I believe they have already gone back home to Mer before us. I will need to check with my wife if she had heard the dûm at that appropriate time and date.'

Spirits use the falling star as a way to signal their presence, say goodbye or say hello to people.

The Maier is featured in traditional songs and dances, which are performed on special occasions. It is also referred to as a fire dance, as the dancers are holding lit torches made of dried and bound coconut leaves, which they smack together as they dance to give off the uir-uir. There are two movements: the *adalé* and the *arílé*. The adalé is slower and is meant to bring in the audience, while the arílé is louder and livelier. Only a few of the Elders still know the traditional Maier dances. Uncle Alo showed concern that the dances had not been performed on the island in a very long time, meaning that younger generations did not know them. He feared that unless they are performed more frequently, this knowledge will disappear.

In 2018, I was contacted by Clive Oppenheimer, a geology professor from Cambridge University. He was collaborating with legendary filmmaker Werner Herzog on a new art-style documentary about meteors, titled *Fireball: Visitors from darker worlds*. They wanted to film two segments in Australia, and the first was slated to be filmed at Wolfe Creek crater (which we will discuss later). They were curious about an idea for a second filming site. The Maier dance seemed ideally suited. After discussing it with the local council, the Elders and community agreed, and we began planning to film in August of 2019.

As with many plans, things can change quickly and unexpectedly. The Maier dance—which originated on Mer—had not been performed on the island in decades. As Uncle Alo had warned me a few years earlier, none of the dancers knew it and no one was designated to perform on camera. Despite initial panic, a local councillor named Aven Noah recruited four local dancers to learn and perform the arílé of the Maier dance that evening. Uncle Alo spent the next few hours teaching them the choreography.

The dance had to be performed at dusk and sunset was fast approaching.

Uncle Alo and a dozen community members gathered to sing and accompany the dancers using traditional drums. The Maier dance concludes the documentary. What you see on film is the very first time those men performed that dance. It was also the first time it had been performed at home on Mer in half a century.

When stars strike

Stones falling from the sky is an ancient concept, but not one that was widely accepted by the scientific community until the early nineteenth century. On 26 April 1803, thousands of meteorites fell over Normandy, France—an event witnessed by a great number of people. A team led by Jean-Baptiste Biot was sent to investigate the stones. Their analysis proved they were of extraterrestrial origin. Before this, the idea that stones fell from the sky was considered plausible by some but not widely accepted by Western science, as there was no definitive ‘proof ’. Even after this, it was not until the early twentieth century that the scientific community began to accept that meteorites formed the large bowl-shaped structures we now call ‘craters’, such as ‘Meteor Crater’ in Arizona.

Over the last century, an entire branch of study has emerged to study this phenomenon, called *meteoritics*. This is essentially the study of everything in the Solar System smaller than a planet or moon: asteroids, comets and meteoroids. *Asteroids* are rocky space debris bigger than 10 metres in diameter and are mostly found in the region between Mars and Jupiter—the asteroid belt—but can be found all over the Solar System. If they are made mostly of ice and dust, they are called *comets* and tend to be in a region called the Kuiper belt, in the far outer reaches of the Solar System, beyond Neptune. A few of them have orbits that bring them close to the Sun. As comets reach the inner regions of the Solar System, solar wind begins melting them, creating a giant trail of dust and debris that extends millions of kilometres into space. We see this as the comet’s tail, which always points away from the Sun.

Comets are commonly associated with fear, death, omens, malevolent spirits and evil magic by Aboriginal communities across Australia, as they are in many cultures. A bright comet that was visible in 1901 was seen by Kaitish people of the Northern Territory as a bundle of spears cast down by a star possessing special magic. The people believed it was going to strike the

land and kill everyone but they were all saved by a young man named Ilpailurkna, whose actions caused it to gradually fade away.

Patrick Thaiday is a dance artist whose family are traditionally from the island of Tudu in the central Torres Strait. He created a *zamiyakal* (dance machine) based on a comet. Zamiyakal are mechanical devices held by dancers that demonstrate movement, which enhances the performance. Thaiday describes the comet, or *Kuikuipikal Titui,* as being 'like the head lady to the other stars, the one that leads the way'.

He notes that she only makes an appearance about once every seven years, which draws the attention of lots of people who admire her beauty. 'She moves so gracefully, with passion and pride like a mother followed by her children, one after the other, as she moves across the night sky.' Bright comets are only visible every five to ten years on average and generally appear as a 'smoky' star with a long tail that gradually drifts across the sky from day to day.

Space debris smaller than 10 metres in diameter are referred to as *meteoroids*. When they fall to the Earth, their speed exceeds 15 kilometres per second as they enter the atmosphere, causing tremendous heat and pressure. The burning object creates the visible streak of light astronomers call a *meteor*, commonly known as a 'shooting star' or 'falling star'. Larger bodies can appear extremely bright, blazing across the sky, like the Maier. These are called fireballs.

If the pressure from pummelling through the atmosphere exceeds the tensile strength of the object, it will break apart and fragment, producing the uir-uir described in Meriam traditions. If the energy is great enough, the object will explode in the atmosphere, producing the loud dûm. Astronomers call exploding fireballs *bolides*. If it reaches the ground, it is called a *meteorite*. Most meteorites leave only small dents in the ground, but the larger ones carve out impact craters.

The impact of stones from the sky led to the development of several new ideas: they explained the craters on the Moon and Earth, they caused extinction events and they may have brought the ingredients for life to Earth. The latter point reveals a curious parallel between Indigenous and Western sciences, although we should be cautious in trying to equate them.

During the early formation of the Solar System, extraterrestrial materials rained down on the Earth, seeding our planet with amino acids that formed the basic structure of the proteins necessary for life. Traditions about stones

falling from the sky to bring life are described by some Aboriginal communities across Australia. Luritja artist, Trephina Sultan Thanguwa from the Central Desert, explains that

> all the animals had a big meeting. Who was going to carry the egg of life up to the Universe? The Kulu [louse] was chosen. When you see where the egg of life was carried. Meteorite has landed and dropped, split three ways. This is our memory of the Kulu. And life began.

In the Central Desert, Arrernte traditions describe the formation of a giant landscape feature that represents the point of creation. It is also a place where two knowledge systems come together in a remarkable way.

Impacts of Creation

It was August 2015 when I flew to Mparntwe (Alice Springs) to meet award-winning country musician and radio personality, Warren H. Williams. Warren is a Western Arrernte man, whose family are Traditional Custodians of a place of deep spiritual significance. We met at the local radio station. After introducing ourselves, we discussed music. When he found out I was a drummer, he let me have a crack at the kit in the studio. It was a great way to break the ice and prepare for what we were about to do.

We grabbed some gear, loaded up a truck and headed west. We were on our way to a very peculiar mountain range, which was the focus of a scene for the National Geographic documentary series *The Story of God with Morgan Freeman* that we were about to film. National Geographic had contacted me the previous year about filming locations in Australia for episode 4 of season 1, titled ‘Creation’, which would examine the formation of the world and its relationship to astronomy from an Aboriginal perspective. The producers were especially interested in any places where the Aboriginal and Western scientific descriptions of a place crossed over. For me, it was an easy choice: *Tnorala* (pronounced NOR-a-la).

Tnorala is the Western Arrernte name for a curious circular mountain range, two hours’ drive west from Mparntwe. To geologists, it is known as Gosse Bluff Crater, the remnant of an asteroid impact that dates back more than 142 million years. The mountains are about 5 kilometres wide and tower about 200 metres above the otherwise flat desert. A place of deep spiritual significance to Aboriginal people, it was unquestionably worth sending a film crew to the other side of the planet to learn Arrernte traditions of how the

crater formed.

When we reached the dirt road leading into the crater, we met the film crew, grabbed our gear and set up camp. After building a fire, Warren sat with me and discussed the area's significance. Warren is the nephew of Mavis Malbunka, a Western Arrernte Elder and senior *kurturngula* (caretaker) of the Tnorala story. Years earlier, she was featured in the 2007 short film *Tnorala: Baby falling*, directed by filmmaker Warwick Thornton.

Warren spoke of how in the beginning, a group of women were dancing a ceremony in the Milky Way as stars. One of the women was carrying a baby boy, so she placed him in a *turna* (wooden cradle) and set him down on the edge of the Milky Way. As the women danced, the vibration shook the turna off the edge of the galaxy. The baby fell to the Earth as a blazing star. When he struck the ground, the impact drove the rocks upwards to form the ring-shaped mountain range we see today.

To this day, the baby's parents—the Morning Star and the Evening Star—take turns searching for their lost child. Mavis explains that parents tell their children not to look at the Morning or Evening Star.

> They will make you sick because these two stars are still looking for their little baby that they lost during the dance up there in the sky, the way our women are still dancing. That turna, the one the baby fell out of, is still there. It shows up every winter.

Warren explained where to find the turna falling from the Milky Way. It is traced out by the curve of stars in the Western constellation Corona Australis (the southern crown). He said it was always high in the winter sky and pointed up. And there it was, just under the glow of the galaxy. It looks like the cradle falling from the Milky Way.

We turned in for the night. Around 2 am I awoke to the sound of howling dingoes. Slightly spooked, my eyes popped wide open and I immediately felt a sense of vertigo, as if I were going to fall into the Milky Way. I had never in my life seen so many stars. The galaxy arched high across the sky, appearing as bright as carnival lights. I noticed the waning Moon peeking over the eastern horizon and took a deep breath of the cold, still desert air. I felt a rush of emotion fill my chest. It solidified *exactly* why I became an astronomer. Not because of telescopes, degrees, fancy titles or pretty pictures, but because of the awe-inspiring experience I was having at that exact moment in time.

At dawn we set off for the interior of the crater. Warren took me to the

centre and, following traditional protocol, sang out to the ancestors to let them know our purpose for being there. He explained to me how the falling of the star-baby is what seeded life in Arrernte traditions. That was the moment of creation. It is an ancient story, known long before the arrival of Europeans, scientists or filmmakers. Warren is the custodian of that story and that place, ensuring its safekeeping so future generations can enjoy and learn from it. And he shared that story with millions of people.

Impacts of destruction

The idea that fiery stones falling from the sky will bring the end of the world is widespread. Extinction events have been linked to impacts of asteroids, such as the one that wiped out the dinosaurs some 65 million years ago. In the Bible, Revelation 8:8 describes a great star falling from the sky like a fiery mountain, striking the sea and causing widespread devastation. It turned the waters bitter, which killed a great many people.

A number of Aboriginal traditions describe a similar scenario, and most of them hold a warning against disobeying traditional Law. In Wurundjeri traditions of Melbourne, the creator-ancestor Bunjil cast down a fiery star as punishment for people showing disrespect and breaking Law. It formed a ‘bottomless pit’ called *Buckertillibe*. North of Sydney at Lake Macquarie, Fennel Bay is home to a petrified forest called *Kurra Kurran*. In Awabakal traditions, it represents the remnants of a fiery object cast down by a sky-being as punishment for people breaking social taboos. In Wardaman traditions of the Northern Territory, if Law is not followed, the evil being *Utdjungon* will emerge from the Coalsack Nebula and fall as a fiery star to destroy the Earth.

Traditions about fiery stars falling from the sky and killing the people are not restricted to what some may consider allegory, symbolism or ‘myth’. In some cases, traditions record events that people witnessed and experienced. In the remote Central Desert of Australia’s Northern Territory lies a site of ancient origin that tells the story of a disaster from the skies. It is a unique and curious landscape. At the centre are what non-Aboriginal locals called ‘blowholes’—three large, interconnected depressions with raised rims, around which small metallic fragments were once scattered (which have been mostly pilfered by prospectors, locals, scientists and tourists). With smaller depressions scattered around an area of a square kilometre, they have clearly

been carved out of the land by some catastrophic event.

Known to Westerners today as the Henbury Craters, the site features more than fifteen craters of various sizes. They were formed by a nickel/iron asteroid that blazed across the sky, breaking apart before striking the land. The impact set the land ablaze and blasted debris and meteorite fragments across the area, causing untold destruction. It had long been known to local Aboriginal people, but Westerners did not establish its cosmic origin until the early twentieth century.

When station managers first stumbled across the curious site in 1899, they were unsure what they had found. It lies on the boundary of Arrernte and Luritja lands, and Aboriginal people would not venture near the site, indicating it was a place of taboo. Newspapers reported that the people 'have no legends or stories regarding the place, nor do they appear particularly interested in it'.

Over the years, local interest continued to grow. In 1916, a local prospector named James Mitchell noticed a curious fragment of metal at a blacksmith's. It was made of iron, but also contained nickel—a combination of metals not naturally found on Earth except by the fall of meteorites. He was told that it came from the curious 'blowholes' out at Henbury Station. In 1921, Mitchell befriended a local Aboriginal man and asked to accompany him to the blowholes. Mitchell said the Aboriginal man would not 'venture within half a mile or camp within two miles of them'—then revealed why.

The Aboriginal man explained how this was where 'A fiery devil ran down from the Sun and made his home in the Earth. He will burn and eat any bad blackfellows.'

He described this as *'Tjintu waru tjinka yapu tjina Kurdaitcha kuka'* in the Luritja language. These terms roughly translate to *tjintu* (Sun), *waru* (fire), *tjinka* (dead or 'devil'), *yapu* (a rock), *tjina* (which indicates a 'foot action' like walking or running), *Kurdaitcha* (powerful spirit that punishes evildoers) and *kuka* (eating meat).

Mitchell also claimed that Aboriginal people did not drink rainwater that pooled in the bottoms of the larger craters, as they feared the 'fire-devil' would fill them with a piece of iron. Years later, he sent the metal fragment to The University of Adelaide. It drew the attention of a young geologist named Arthur Alderman, who organised a scientific expedition to the site in May 1931. Alderman recognised that the 'blowholes' had formed from the impact of a large meteorite, kicking off the study of meteoritics in Australia.

The story was plastered on newspaper headlines across the globe. It gave credence to the belief among local non-Aboriginal people that the craters had formed from a catastrophic cosmic impact. It strongly indicates a living memory of the event, but how long ago did it occur? Geoscientists analysed samples from the craters and, using radiometric dating techniques, revealed that they formed around 4200 years ago.

The craters are known today as *Tatyeye Kepmwere* (*Tatjakapara*) in the Arrernte language, but their traditions are rather different from those of the Luritja. This is a place that marks the end: a scarred landscape of death and destruction that has remained in the people's consciousness for over 200 generations.

Old ways informing new science

Despite their destructive nature, not all cosmic impacts represent the 'end times'. As we learned before, some represent the beginning. The Maier dance is where the Herzog–Oppenheimer film *Fireball* ends, but Australia's most famous meteorite crater—Wolfe Creek—is where it begins. At the start of the film, Jaru woman Katie Darkie explains the importance of the site to the Jaru people while showing a painting of the site. The 900-metre-wide crater in the Great Sandy Desert of Western Australia is known as *Kandimalal*. It is a place of many stories and many meanings. It is a focal point of art and intrigue. It is also a place where ancient stories have guided scientific research.

Western scientific 'discovery' of the crater goes back to 1947 when an American geologist, Dr Frank Reeves, spotted it during an aerial survey. The Western name comes from a nearby creek, which itself was named after Robert Wolfe, a gold-rush prospector. Dr Reeves published a scientific paper on the crater two years later. His daughter, Dr Peggy Reeves Sanday, is Emeritus Professor of Anthropology at the University of Pennsylvania. She visited the crater in the late 1990s to retrace her father's footsteps and learn from the local community about the place. The Jaru shared their knowledge with her, and she commissioned artworks from them. This collaboration was published in her 2007 book *Aboriginal Paintings of the Wolfe Creek Crater: Track of the Rainbow Serpent.*

Dr John Goldsmith is a photographer and scientist from Perth who has worked with local Elders since the late nineties to document their knowledge

of the crater. He completed a PhD in 2014, and a large part of his research involved interviews with local Elders about the crater. These Elders, many of whom have since passed, shared two general themes about how Kandimalal formed: some regard it as where a large serpent emerged from the ground, while others regard it as a place where a star fell to the ground.

The crater is the focus of Jaru artworks and songs about its formation. Every physical feature has meaning and importance. Elders, such as S. Brumby and J. Jugarie, describe it as where a star fell to earth, described in a song shared with Dr Goldsmith that repeats three words: *warda* (star), *wandinga* (fall down) and *morungai* (the ground).

Jugarie, who passed away in 1999, explained the story behind the crater to Dr Goldsmith. Long ago the Moon rose behind the Evening Star. Becoming too hot from the Moon, it quickly fell to the Earth, causing a brilliant flash and a deafening explosion that shook the land. This greatly frightened the people and years passed before they returned. When they did, they saw the spot where the star had fallen. Jugarie expanded on this for Professor Reeves Sanday in her book: 'A star bin fall down. It was a small star, not so big. It fell straight down and hit the ground. It fell straight down and made that hole round, a very deep hole. The earth shook when that star fell down.' Elder S. Sturt explained, 'That star is a Rainbow Serpent. This is the Aboriginal Way. That snake travels like stars travel in the sky. It came down at Kandimalal. I been there … I still look for that crater.'

In local traditions, bright meteors indicate the death of a person, much like the Meriam traditions of the Torres Strait. Jugarie taught Dr Goldsmith how the people see these meteors and wait for the sound they make.

> 'Coolungmurru', the name of that [star] when he hit the ground. When the star, when he move, that's the one I'll tell you, that star been move, and he made a big light, you know, when he run, on the top, and the light go off, and they listen now, keep quiet everyone, we listen for the Coolungmurru now, listen for a while, and when he hits the ground, he shakes this country … and that's it, that's the Coolungmurru. That's a warda … a star been fall, we call him Coolungmurru, that a one, shooting star.

Listening for the booming sound of the shooting star is also similar to Meriam traditions of the Maier—something shared by a number of Aboriginal communities across Australia. Whether exploding in the atmosphere or striking the ground, these bright meteors create a brilliant light and their sound can shake the land. A modern example of this is the well-documented Chelyabinsk meteor that exploded over Russia on 15 February

2013. A much larger event occurred over Tunguska, Siberia, on 30 June 1908.

The Tunguska meteoric explosion flattened 80 million trees spread out over an area of 2150 square kilometres. It created a sound described as ‘artillery fire’ and a shockwave so powerful that people hundreds of kilometres away were knocked off their feet as windows shattered. It produced so much light that people in England—5800 kilometres away—could read newspapers at midnight, and it registered as a magnitude-5 earthquake.

The event was so enigmatic that it fuelled speculation and conspiracy theories for more than a century. Explanations ranged from the explosion of a small comet to a mini-black hole entering our atmosphere to the crash of an alien spacecraft. Nearly twenty years passed before a team of Russian scientists undertook an expedition to the blast site and found that the airburst was alive in the memory of the local Evenki people, who saw it as the vengeful act of an angry sky deity and considered the site to be deeply sacred. Their accounts of the event helped scientists learn more about the meteor’s trajectory, scale of destruction, and impact on the local and regional environment.

The link between the destructive formation of Kandimalal and its accompanying traditions of a falling star indicated that this, too, may have been a witnessed event. Some community Elders describe the crater in different terms, so there is no single, unifying interpretation. But it poses an interesting question: when did this impact occur?

The late geologist Eugene Shoemaker estimated it to have formed between 30,000 and 300,000 years ago. It was not until 2019 that a team of geoscientists utilised new dating techniques to come to a more precise age. The team, led by Professor Tim Barrows from the University of Wollongong, south of Sydney, were already interested in determining the age of the crater, but the idea that Aboriginal people may have witnessed its formation was an additional motivation.

The different scientific techniques used by the team revealed ages ranging from 86,000 to 128,000 years. Their analysis concludes that the crater probably formed about 120,000 years ago. It seems the impact probably occurred before people migrated to Australia, but it suggests the Jaru deduced how it formed based on its morphology and demonstrates how Indigenous Knowledge can guide Western scientific research. The geologists were

motivated, in part, to study the crater's age because of the Aboriginal traditions that suggested it was younger than 300,000 years. And that was exactly what they found—by a significant margin. It is a prime example of how these knowledge systems can work together.

From stars to stones

Meteorites have been identified across Australia because of their descriptions in Aboriginal tradition. Several of these were recorded as witnessed falls. A 32-kilogram meteorite was found near Stockinbingal, New South Wales, in 1855. The astronomer and director of Sydney Observatory at the time, Henry Chamberlain Russell, wrote that:

> Some time back … this aerolite [meteorite], according to Aboriginal lore, descended on earth and half buried itself there at the head of Bland Creek, which has its principle [*sic*] source in the vicinity of Stockinbingal. It is a huge block of stone … The [people] were terribly afraid of it, believing it to be possessed of supernatural powers. So they called the strange visitor 'Yeo Yeo', a synonym for 'Devil-Devil', and Yeo Yeo Creek it remains today.

None of the people involved in its 'discovery' or analysis ever mentioned the Aboriginal story crediting them as the original discoverers. Still other craters were long known by Aboriginal people, or even 'discovered' by them in modern times, though this is rarely credited.

The smallest individual meteorite structure in Australia is the 25-metre-wide Dalgaranga crater near Yalgoo, in the Murchison region of Western Australia. It was found by an Aboriginal stockman named Billy Seward in 1921, who almost ran into it while riding a horse at full gallop, but it was not formally documented until many years later. A number of meteorite fragments and flint flakes were identified around the crater. Dalgaranga meteorites, which are a rare form of stony iron mesosiderite, have been found at locations up to 200 kilometres away, showing that the site was long known to Aboriginal people and that the meteorites formed some component of the local traditional economy. The crater's discovery is commonly attributed to Gerard Wellard, who managed the Dalgaranga Station where the crater was found and located meteorite fragments around the area. Its age is not currently known to Western science but could be as young as 3000 years based on Eugene Shoemaker's initial estimate.

In western Arnhem Land lies a 1.6-kilometre-wide crater known as Liverpool, named after a local river. It is called *Yingundji* in the Kunwinjku

language, and local traditions regard it as the nest of a giant catfish. This knowledge was shared by two brothers of the Kurulk clan with Eugene Shoemaker and his astronomer-wife Carolyn Shoemaker (co-discoverers of the famous comet Shoemaker-Levy 9 that impacted Jupiter in 1994). The Shoemakers said that when they reached the site by helicopter, they saw several Aboriginal paintings on the inside walls of the crater. One of the motifs was of the giant catfish.

Not all meteorite impacts witnessed by Aboriginal people are from the distant past. Aboriginal people witnessed the fall of the Munpeowie meteorite near the Strzelecki Desert; they saw it ‘fall to the south-west’. A short time later, an enormous meteorite weighing well over a metric tonne was found 70 metres away from an elliptical hole in the ground measuring 5 metres by 3.7 metres long and more than a metre deep. It was reported to have first been identified by an unnamed Aboriginal man in 1909.

What we see in this chapter is that Torres Strait Islander people observe and interpret the properties of meteors and comets and assign meaning to them, with applications to culture, spirituality and identity. We see that Aboriginal people long ago recognised that unique landscape features were places where celestial objects fell to the Earth with sometimes disastrous results. Some of these events were witnessed firsthand, the memory of which has survived in oral tradition to the present day, thousands of years later. For other sites, deductive reasoning was central to explaining their formation. Oral traditions of objects falling from the sky led to the identification of meteorites by Western science and guided some to reconsider the ages of these impacts—with startling results.

Most importantly, we have shown a wide breadth of examples of how Indigenous Knowledges contain complex layers of scientific information. It was derived through close and careful observations, logical deductive reasoning, experimentation, analysis and collective wisdom, all of which was passed down through oral tradition for thousands of years.

And there is a great deal more we can learn if we simply listen.

Epilogue

'We always have to respect that star knowledge. We always have to respect that spirit. We are very connected to Unci Maka, the grandmother Earth.'

—Arvol Looking Horse, Lakota Elder and spiritual leader

We hope this book has guided readers on a journey to understanding and appreciating the depth and complexity of Indigenous Knowledges of the stars, and how these ancient understandings of the Universe are living and thriving today. To move forward, we must learn to understand, appreciate and respect these systems of knowledge for their inherent value. We are excited about Indigenous and Western ways of knowing working together in collaborative and respectful ways to provide innovative solutions to pressing issues that impact us all.

We still have a long way to go. Only a handful of First Nations people have doctoral degrees in Western astronomy or work in the field of Indigenous astronomy. As of this book's publication, there is still only one PhD-qualified Aboriginal astrophysicist in Australia: Dr Stacy Mader, a Gidja man from Western Australia who earned his doctorate from the University of Wollongong in 2000. Dr Mader has been employed by the CSIRO since 1999, working as a radio astronomer at Parkes Observatory in New South Wales researching star formation and supporting NASA space missions to Mars.

In Aotearoa/New Zealand, Dr Pauline Harris was the first Māori person to earn a PhD in physics. After a career searching for planets orbiting distant stars, she now focuses her academic career on Māori astronomy at Victoria University of Wellington and chairs the Society of Māori Astronomy Research and Traditions (SMART). In 2020, Dr Motheo Koitsiwe became the first African to earn a PhD in Indigenous Astronomy, which he completed at North-West University in South Africa with a thesis on Batswana astronomy. In that same year, Dr Annette Lee completed her PhD at the University of the Western Cape, also in South Africa, with a thesis on the integration of Indigenous Knowledges into introductory astronomy courses.

In the United States and Canada, work in Indigenous astronomy is increasingly driven by First Nations scholars and Elders, such as Annette Lee, Wilfred Buck, Arvol Looking Horse, Nancy Maryboy and David Begay. There is a rapidly growing interest in this topic on a global scale, and these scholars are leading the way. They bring a lived experience to this work and embody the concept of Etuaptmumk—'Two-Eyed Seeing'.

A new generation

In Australia, there is a rapidly growing generation of Aboriginal scholars earning degrees in astrophysics, engaging in research and scholarship, and popularising work in this space. By taking advantage of new technologies and social-media platforms, they have become global personalities with mass followings. Kirsten Banks is a Wiradjuri woman pursuing a PhD in astrophysics at UNSW. She is a TEDx speaker and TikTok sensation with hundreds of thousands of followers across multiple platforms and has appeared on numerous TV programs, including ABC's *Q&A* panel with Brian Cox.

Karlie Noon is a Gomeroi woman and a Superstar of STEM who appeared on the series *Stargazing Live* with Brian Cox in 2017 and dozens of TV and radio programs. She is the first Aboriginal person to earn a double degree in physics and mathematics in Australia, graduating from The University of Newcastle. She completed a master's degree in astrophysics and is pursuing a PhD at the Australian National University (ANU) in Canberra.

Krystal De Napoli is a Gomeroi woman and award-winning science communicator who has appeared on TV programs such as ABC's *The Drum* and hosts her own radio program called *Indigenuity*. She earned a degree in physics and is completing an Honours program in astrophysics at Monash University in Melbourne. Krystal and Karlie teamed up to write a book on astronomy as part of The First Knowledges series.

First Nations people in Australia are studying astronomy and meteorology from a multitude of perspectives. Gomeroi/Euahlayi man Pete Swanton earned a degree in astrophysics from ANU and is now pursuing a master's degree researching Indigenous astronomy and dark sky studies. Tina Leaman is a palawa woman and artist from Tasmania working on projects in Aboriginal astronomy with her husband and PhD candidate, Trevor Leaman. Barkindji artist John South investigates the intersection of Aboriginal

astronomy and visual art, and he developed the *SKYWORLD* exhibition. William Stevens is a Muruwari man who focuses on traditional knowledge and craft, and he was Sydney Observatory's first Aboriginal star guide. Wirangu man and astrophysics graduate Peter Reeve works at the Australian Bureau of Meteorology to predict severe weather, while Yorta Yorta ecologist Jessie Ferrari is conducting research on astronomical components of traditional seasonal calendars at The University of Melbourne.

Cosmic nomenclature

One of the exciting outcomes of this work focuses on the recognition of Aboriginal and Torres Strait Islander names for stars and asteroids by the International Astronomical Union (IAU). The IAU is the global organisation responsible for, among many things, assigning names to celestial objects for use in the scientific literature. Of course, all cultures have their own names for celestial objects, and the IAU's work does not erase this. It is an imperfect system undergoing constant revision, with growing teams of Indigenous members in the working groups.

In 2016, the IAU formed a working group to assign one name for all the visible stars in the sky. The original group, which consisted of only a handful of members, including me, set about formalising these names. Most of them are derived from Arabic, Roman and Greek names. Indigenous names were not well represented, so we aimed to correct this. In 2017, more than a hundred star names from Indigenous cultures across the world were formally approved by the IAU. Four of them were Aboriginal names from two languages: Wardaman and Wergaia.

Wergaia Country is in north-western Victoria, and the star's name is Unurgunite (Sigma Canis Majoris, aka Nganurganity). This is the jacky lizard who attacked Mityan the Moon, as discussed in Chapter 3: The Moon. The Wardaman names come from Yidumduma Bill Harney, and include Wurren (Zeta Phoenicis), Larawag (Epsilon Scorpii) and Ginan (Epsilon Crucis). The latter star is the fifth brightest star in the Southern Cross. This created quite the media storm, as the Southern Cross is the most recognisable and prominent constellation in the public psyche. It is featured on the flag of Australia (and on the flags of Brazil, New Zealand, Papua New Guinea and Samoa) and, since the mid-2000s, has become a symbol of nationalism and colonial pride to many people.

This issue was the focus of Warwick Thornton's 2017 film *We Don't Need a Map*. Aboriginal astronomy was featured throughout this documentary. I was involved in the film and had quite an enjoyable experience with the ultra-laid-back but extremely talented Thornton. It premiered as the opening feature for the 2017 Sydney Film Festival. At a 2018 screening in Melbourne, I bought a ticket and tried to slip into the theatre inconspicuously. Warwick recognised me and came over to say hello. I told him about the IAU formalising the Wardaman star name Ginan for the fifth star of the Southern Cross. He asked me to make an announcement to the crowd at the film's conclusion, which was a heartfelt gesture. Wardaman Elder Yidumduma Bill Harney was a central figure in the film, and it was he who provided and approved the Wardaman star names.

Another batch of IAU star names was announced in 2018, which included the Wardaman name Gudja (Kappa Serpentis), the Kamilaroi/Euahlayi name Guniibuu (36 Ophiuchus) and the Mursi name Imai (Delta Crucis), which was discussed in Chapter 6: The Seasonal Stars. Guniibuu was provided and approved by Ghillar Michael Anderson. In 2018, the IAU sponsored an international initiative where each country in the world could nominate a name for a distant star and its known planet. The NameExoWorlds campaign in Australia was led by Mount Burnett Observatory in the Dandenong Ranges, east of Melbourne. The public could propose names and vote on them. Jaeden Williams, a Boon Wurrung man, nominated the name Bubup (child) for the star, and Yanyan (boy) for the planet. They were voted as the winners for Australia and were approved by the IAU. Bubup (HD 38283) is a faint, magnitude 6.7 star in the Western constellation Mensa. Yanyan (HD 38283 b) is a planet with a mass similar to Saturn, which orbits Bubup every 363 days.

Stars are not the only celestial objects formally recognised by their Aboriginal names. Over the decades, astronomers have amassed databases with literally hundreds of thousands of confirmed asteroids. Most have catalogue names that indicate the year they were found, the time of year and their order on the list of asteroids found in that session. A few of the largest asteroids have been named after figures in Greek mythology. For a period, the scientific community referred to asteroids as 'Minor Planets' but since 2006 now refers to asteroids and comets as 'small Solar System Bodies'. Some of the smaller asteroids are given more formal and personal names. This is managed by the IAU, which maintains a Working Group on Small

Body Nomenclature.

In 2020 and 2021, six asteroids were formally named after Aboriginal and Torres Strait Islander Elders, academics and a community. They include three Elders (Segar Passi, Yidumduma Bill Harney and Ghillar Michael Anderson), two academics (Marcia Langton and Martin Nakata) and the entire Meriam community of the eastern Torres Strait. At this point, you should already be familiar with all of them!

Dozens of landscape features on planets and moons in our Solar System have been assigned Indigenous names from Australia and around the world by the IAU. More asteroid names are also in the process of being formally recognised by Indigenous names. This is a small but important step in acknowledging and respecting First Peoples who are active in sharing and safeguarding traditional star knowledge.

The National Curriculum

The inclusion and integration of Indigenous ways of knowing into school curriculums and university degree programs is rapidly growing in popularity around the world. Educators are recognising the important contributions of Indigenous Knowledges in education and in advancing mutually beneficial scientific research in a respectful, collaborative and inclusive way.

In 2018, Professor Marcia Langton led a major initiative to develop education modules for primary and secondary schools in Australia on Indigenous Knowledge with respect to three different areas: fire, water and astronomy. Our work resulted in astronomy modules for seven core subjects (such as science, mathematics, humanities, health and art) for both primary and secondary schools. They include in-class activities and are linked to specific curriculum requirements for each year level. The modules for teachers are available at:

indigenousknowledge.unimelb.edu.au/curriculum

Learning more

Across the world, new programs are educating the public about Indigenous astronomy. Dr Annette Lee developed the Native Skywatchers initiative in 2007 with an overarching goal to ‘communicate the knowledge that

Indigenous people traditionally practised a sustainable way of living and sustainable engineering through a living and participatory relationship with the above and below, sky and earth'. Readers can learn more about this pioneering initiative at:

www.nativeskywatchers.com

Those interested in learning about the complex star knowledges of the Māori people of Aotearoa/New Zealand, as well as the new national holiday marked by Matariki, can learn more on the website for the Society of Māori Astronomy Research and Traditions (SMART):

www.maoriastronomy.co.nz

Readers can learn about complex Polynesian navigational techniques and the global voyages of traditional Hōkūleʻa seacraft from the Polynesian Voyaging Society:

www.hokulea.com

Readers wanting to learn more about the research, programs and outcomes in Aboriginal and Torres Strait Islander astronomy in Australia can visit:

www.aboriginalastronomy.com.au

Finally, everyone can support the next generation of young Indigenous scientists by contributing to Deadly Science. ('Deadly' is a term used by Aboriginal and Torres Strait Islander people meaning 'awesome', 'amazing' or 'excellent'.) The charity sends science, technology, engineering, and mathematics (STEM) books and educational materials to Aboriginal and Torres Strait Islander children in schools around the country. It was founded Corey Tutt, a Kamilaroi man and 2020 Young Australian of the Year.

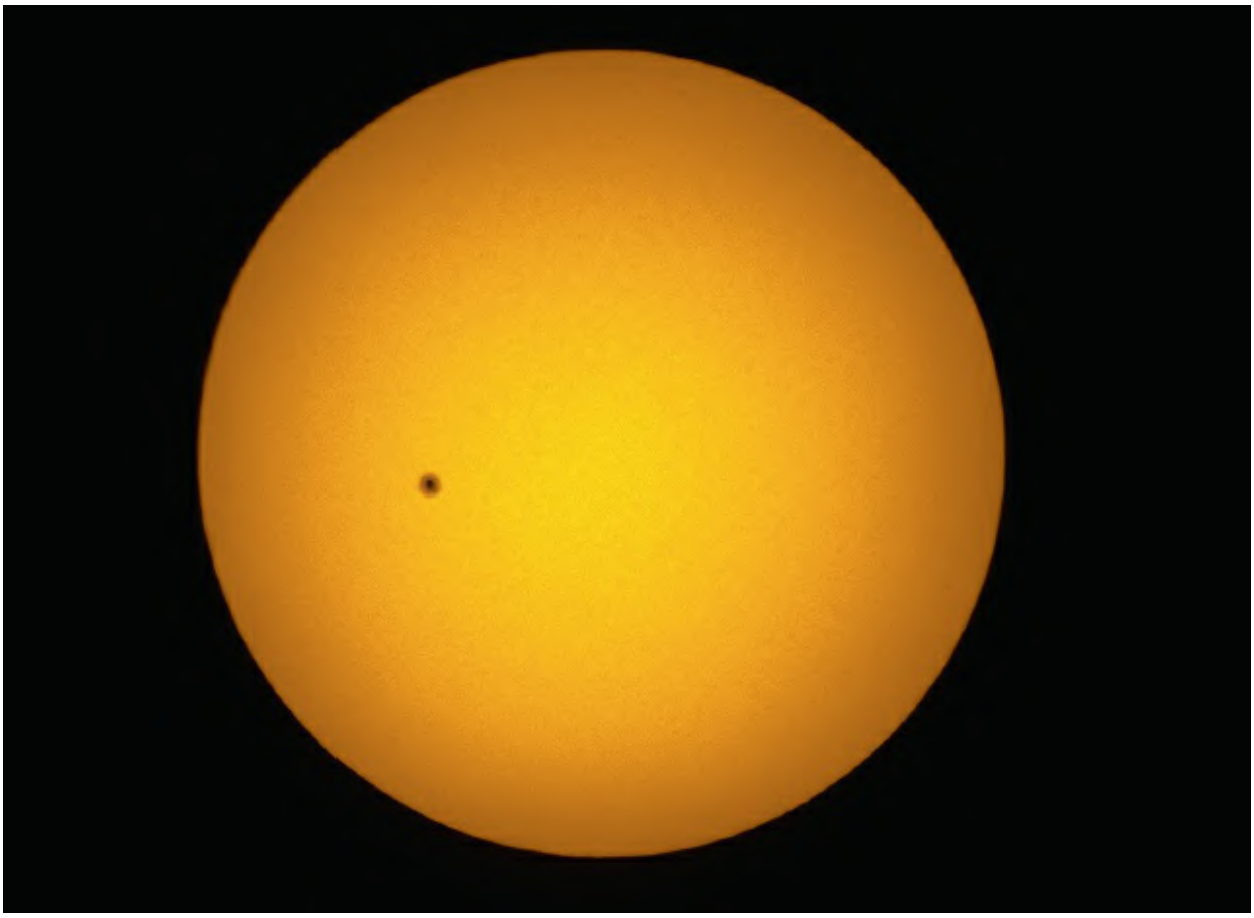
www.deadlyscience.org.au

Lakota astrophysicist Dr Annette S. Lee teaching traditional star knowledge in front of one of her artworks. (Courtesy of Annette S. Lee)

Lakota Elder Jim Yellowhawk under the path of the Milky Way. (Prisma by Dukas/Alamy)

Mer (foreground), Dauar (upper right) and Waier (upper left) in the Torres Strait. (Duane Hamacher)

Our Culture is Important by Meriam Elder and artist Segar Passi (2012). It shows knowledge of the sky being taught to younger generations. (Courtesy of Segar Passi and Gab Titui)



A sunspot photographed on 15 April 2019. (Courtesy of Peter Lieverdink)

K’inich Ahaw, the Mayan Sun-god at Copán Ruinas in Honduras. Spots on his face can be seen under his right eye. (Alberto Paredes/Alamy)

The thirteen towers of Chankillo in Peru, built by the Casma/Sechin culture. The Sun sets over each of the towers over a year. (Werner Forman Archive/Alamy)

Calcite (Iceland spar), a mineral used by Norse navigators to locate the Sun behind cloudy skies. (Courtesy of Arni Ein)

The northern lights (aurora borealis) over Alaska, used by Iñupiat people to navigate, as streams tend to run east to west. (Lucas Payne/Alaska Stock/Alamy)

Celestial navigation aid carved into the deck of the *Marumaru Atua*, a modern *vaka* built in the style of traditional Polynesian ships. (Chester Voyage/Alamy)

Kerkar Meb 1 by Meriam Elder and artist Segar Passi (2011). The painting shows the angle of the waxing crescent Moon after sunset during the dry season. (Courtesy Segar Passi and QAGOMA)

Kerkar Meb 2 by Segar Passi (2011). This painting shows the angle of the waxing crescent Moon after sunset during the wet season. (Courtesy Segar Passi and QAGOMA)

Eclipse of the Moon on 8 June 2006. The red colour of the Moon is often associated with blood and death. (Peter Lieverdink)

A Moon halo, used by many First Peoples to forecast approaching rain. (Kerstin Langenberger/Alamy)

Venus and the crescent Moon in conjunction, with the glow of earthshine visible on the Moon. (Peter Lieverdink)

Ba̲numbirr (Morning Star) poles on display at the Gallery of Modern Art in Brisbane. (Duane Hamacher)

Zodiacal light stretching into the sky as seen from La Silla Observatory, Chile. (Reda & Co./Alamy)

Comet McNaught over the Australian outback. The wispy tails of comets are often conceptualised as smoke, hair or a bundle of spears. (Excitations/Alamy)

Gawarrgay (the celestial emu in the dark region of the Milky Way), drawn by Euahlayi Elder Ghillar Michael Anderson (2014). (Courtesy of Ghillar Michael Anderson and Stellarium)

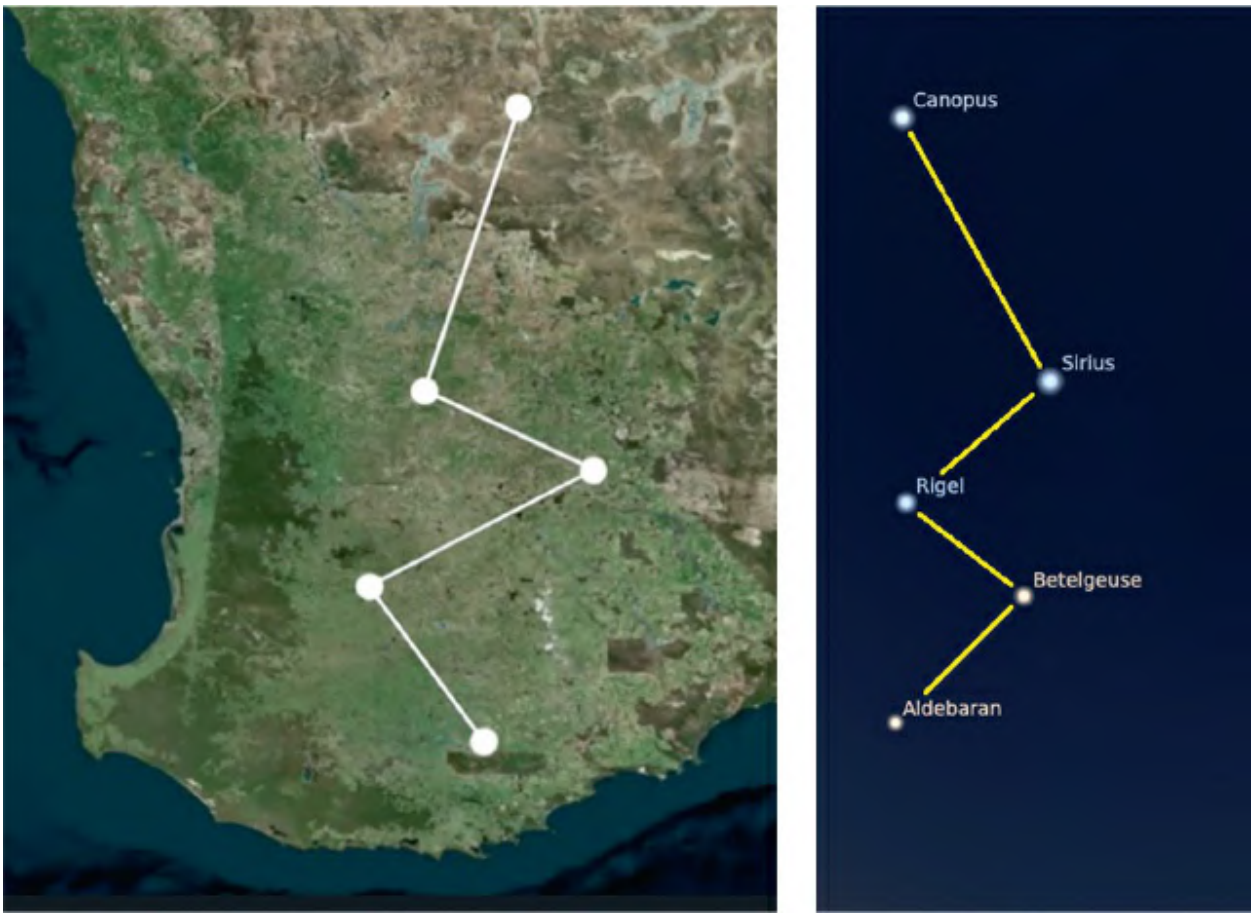
Kaygasiw Usul (the shovelnose ray in the Milky Way), headdress by Alick Tipoti (2014), an artist and Zenadh Kes islander from Badu in the western Torres Strait. (Courtesy of Alick Tipoti and Australian National Maritime Museum)

The Pointer stars, Alpha and Beta Centauri (left), and the Southern Cross (right), with the dark Coalsack Nebula in the centre, representing the head of the celestial emu/rhea. (Alan Dyer/Stocktrek Images/Alamy)

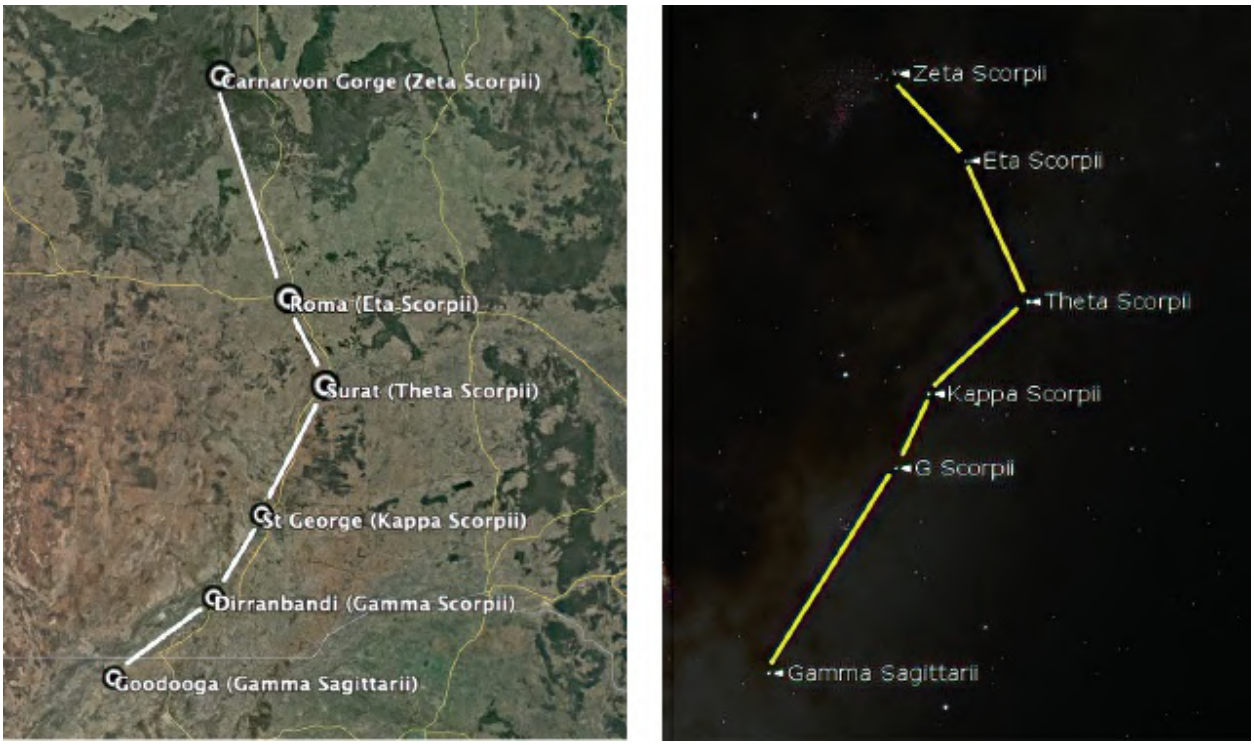
Eta Carinae, the blue-giant star that erupted in the 1840s and was observed by Boorong people who incorporated into their oral traditions. (N. Smith, University of Arizona, and J. Morse, BoldlyGo Institute, NASA/ESA)

Tnorala (Gosse Bluff), a giant impact crater described as where a celestial baby fell to Earth as a star in Arrernte traditions of Central Australia. (Jean-Paul Ferrero/ AUSCAPE/Alamy)

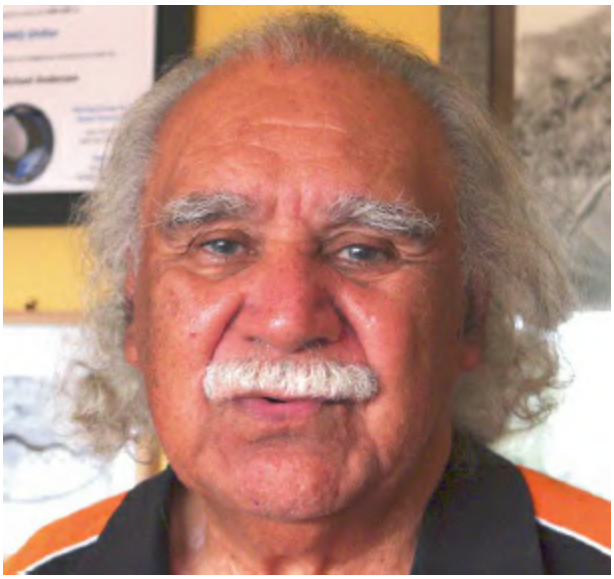
Kandimalal (Wolfe Creek crater), the site of several different Jaru traditions in Western Australia. (Russotwins/Alamy)



An Aboriginal Songline in Western Australia mirrored in the stars, as described by Noongar Elder Dr Noel Nannup. (Duane Hamacher, using Google Earth and Stellarium)



Travel routes across south-eastern Queensland mapped out in the stars, as described by Euahlayi Elder Ghillar Michael Anderson. Roads and highways are represented by yellow lines. (Robert Fuller and Duane Hamacher, using Google Earth and StarryNight)



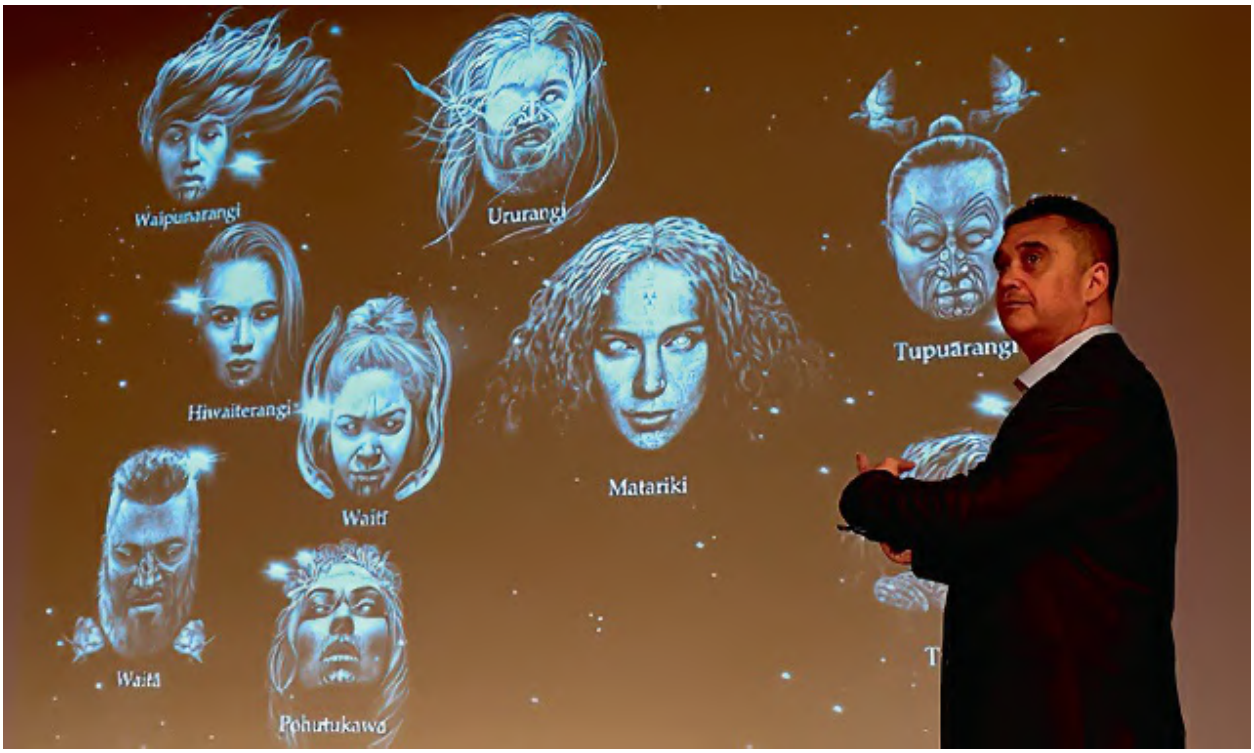
Uncle Ghillar Michael Anderson, a Senior Law Man and leader of the Euahlayi Nation in New South Wales, Australia. (Ellie Gilbert)

David Bosun, a Mualgal man and Senior Artist at Moa Arts in the western Torres Strait, Australia. (Courtesy David Bosun/ Cairns Indigenous Art Fair)

Escaping to the Milky Way by Ngarrindjeri artist Cedric Varcoe (2013). It depicts Waiyungari escaping to the stars with two women by a spear cast into the Milky Way. (Courtesy Cedric Varcoe)

Meriam Elders, Knowledge Holders and dancers on Mer after performing the *Gedge Togia* Moon dance in 2015: (*clockwise from top left*) Alo Tapim, Michael Passi, John Barsa, Rocky Sambo and Bradley Noah. (Duane Hamacher)

Meriam Elders and Knowledge Holders on Mer posing in front of a new telescope for the community in 2018: (*left to right*) Ron Day, William Bero, Segar Passi and Andrew Passi. (Duane Hamacher)



Rangi Mātāmua lecturing about Matariki, the stars of the Pleiades, which signal the Māori New Year. (Courtesy Rangi Mātāmua)

Pipe Ceremony in the Stars by Lakota artist and astrophysicist Dr Annette S. Lee (2011). (Courtesy Annette S. Lee)

Glossary of astronomical terms

Altitude: The angle of a celestial object in the sky measured in degrees relative to the horizon (0 degrees) up to 90 degrees at the zenith (top point on the celestial dome) or down to −90 degrees at the nadir (bottom point of the celestial dome).

Amplitude (tides): The difference in displacement between the peak and trough of a wave; the difference between high tide and low tide.

Angular diameter: The apparent width of a distant object. The Sun is 400 times wider than the Moon but is also 400 times further away. This coincidental ratio means the angular diameter of the Sun and Moon are about the same: around half a degree.

Annular eclipse: When the Moon is in front of the Sun but the angular diameter of the Sun is slightly larger than that of the Moon, it appears as a dark disc surrounded by a bright ring (annulus), which is the outer edge of the Sun in the background.

Aphelion: The point in the orbit of a celestial body when it is furthest from the Sun.

Apogee: The point in the orbit of the Moon when it is furthest from the Earth.

Apparition: The period of time a celestial object is visible in the sky, usually lasting from weeks to months.

Asterism: A pattern of stars that is not one of the 88 recognised Western constellations.

Asteroid: A rock in space that is over 10 metres in diameter.

Aurora: Light display caused by charged particles of solar wind being channelled to the polar regions by Earth's magnetic field. These particles ionise oxygen and nitrogen molecules in the upper atmosphere, creating light.

Azimuth: The angle along the horizon forming a full circle around an observer, with due north at 0 degrees, due east at 90 degrees, due south at 180 degrees and due west at 270 degrees.

Bayer Designation: A binomial system of naming stars within a constellation based on their brightness within that constellation. The star's brightness is represented by a Greek or Latin letter, followed by the genitive form of its host constellation's Latin name. For example, the Southern Cross constellation is 'Crux Australis', or simply 'Crux', with the genitive form being 'Crucis'. The brightest star in Crux is dubbed 'Alpha Crucis', the second brightest is 'Beta Crucis'. This system was developed by the German astronomer Johann Bayer in 1603 and first published in his star atlas, *Uranometria*. Since constellation boundaries have changed over time, and some stars are variable in nature, this designation does not always represent the appropriate brightness of stars in all instances.

Binary star: A system of two stars that are gravitationally bound to each other. If the stars move in front of each other within our line of sight, they are called eclipsing binaries.

Black hole: A place in space where gravity is so intense, not even light can escape. It is formed by collapsing stars with a boundary called the *event horizon*, the point from which matter and light cannot escape.

Bolide: A bright meteor that fragments and/or explodes in the atmosphere, the latter of which are typically accompanied by a sonic boom.

Cataclysmic star: A star that explodes or violently erupts, ejecting material into space. Novas and supernovas are types of cataclysmic stars.

Celestial dome: An imaginary dome over an observer (or sphere around the observer) on which celestial bodies and coordinate systems can be projected.

Celestial equator: The projection of Earth's equator onto the celestial dome, which is tilted from the ecliptic by 23.5 degrees.

Celestial pole: The projection of the Earth's north and south poles onto the celestial dome, having an altitude of 90 degrees above an observer standing at the pole.

Celestial sphere: The sphere around an observer that uses a projected coordinate system to identify positions of objects in the sky.

Chromatic aberration: An effect caused by pockets of moving air in the Earth's atmosphere, each having slightly different densities and temperatures, altering the refractive index of incoming starlight, causing the star to change colour as it twinkles.

Comet: A celestial body made of ice, dust and rock originating in the outer Solar System that moves around the Sun in an elongated orbit. As it moves closer to the Sun, solar wind evaporates the ice, sublimating it to gas. Comets have a central mass (nucleus) surrounded by a misty envelope (coma) that extends into a stream (tail) in the direction away from the Sun.

Conjunction: The alignment of two planets, or a planet and a star, in the sky that makes them appear close together.

Constellation: A term used to describe groups of stars that form a familiar pattern. Formally, Western science divides the sky into 88 constellations, each with a clearly defined boundary.

Coriolis effect: The pattern of deflection taken by objects in our atmosphere as they travel long distances around the Earth. This effect, due to the Earth spinning on its axis, is responsible for many large-scale weather patterns.

Crater: A geological structure caused by the impact of space debris such as meteorites, comets or asteroids.

Crescent Moon: When less than half of the Moon is illuminated, making it appear as a crescent shape.

Cusps: The pointed tips of the crescent Moon. The cusps always point away from the Sun.

Declination: The projection of the Earth's latitude onto the celestial dome, measured in degrees, arcminutes and arcseconds. An object's declination is zero at the celestial equator and either increases to 90 degrees at the north celestial pole, or −90 degrees at the south celestial pole.

Diurnal motion: The apparent motion of celestial objects moving from east to west caused by the Earth rotating from west to east.

Earthshine: Sunlight reflected off the Earth's atmosphere and onto the Moon's surface.

Eclipse: A transient event that occurs when the Moon moves directly in front of the Sun (solar eclipse) or the Moon moves into the shadow of the Earth (lunar eclipse).

Eclipse season: A time of year when eclipses can occur as the Moon crosses the ecliptic, and the Moon, Earth and Sun are in alignment (syzygy). Two eclipse seasons happen each year, each of which lasts about 35 days. Each season repeats just under six months later. Thirty-eight eclipse seasons will occur within a full Saros cycle of 6585.3211 days.

Ecliptic: The path of the Sun in the sky, marking the plane between the Earth and the Sun.

Elevation: The height of an observer above sea level. Elevation is 0 degrees at sea level and is positive if higher and negative if lower. Not to be confused with 'altitude'.

Ellipse: The non-circular (ovate) shape of a celestial body's orbit. This is measured by the orbit's eccentricity, measured between 0 (a perfect circle) and 1 (a parabola).

Elongation: The maximum angular distance Mercury or Venus will be seen away from the Sun.

Equinox: The midpoint between the solstices when the Sun rises due east and sets due west. Equinoxes

are split between vernal, from the Latin term *vernalis,* meaning spring, and autumnal, from *autumnalis,* meaning autumn.

Fireball: A meteor brighter than Venus.

First Quarter Moon: The phase of the Moon where half of the illuminated side of the Moon faces the Earth that occurs when the Moon is waxing (the left side is illuminated as seen from the southern hemisphere). A First Quarter Moon rises at noon and sets at midnight.

Full Moon: The phase of the Moon where its fully illuminated side is facing the Earth, appearing opposite the Sun in the sky. A Full Moon always rises at dusk and sets at dawn.

Gibbous Moon: When more than half of the Moon is illuminated.

Halo: A visible ring around the Sun (parhelion, or sundog) or Moon (paraselene), caused by the refraction of incoming light by hexagonal ice crystals suspended in the atmosphere. Haloes are typically seen 22 degrees and/or 44 degrees from the Sun or Moon.

Heliacal rising: The first appearance of a star or object in the east at dawn before the rising Sun washes out the star's light.

Heliacal setting: The last appearance of a star or object in the west after the Sun has set.

International Astronomical Union (IAU): The global organisation for the world's professional astronomers to advance all areas of astronomy. The IAU is responsible, among other things, for formalising names for all celestial objects.

King tides: High tides that occur when the Earth is closest to the Sun (at perihelion). This increases the pull of the Sun's gravity, causing exceptionally high tides.

Last / Third Quarter Moon: The phase of the Moon where half of the illuminated side of the Moon faces the Earth that occurs when the Moon is waning (the right side is illuminated as seen from the southern hemisphere). A Last/Third Quarter Moon rises at midnight and sets at noon.

Lunation: The time it takes for the Moon to go through its full set of phases (29.54 days). This is also the Moon's synodic period, or lunar month.

Magnitude: The measurement of a celestial body's brightness using an inverse logarithmic scale. This means the lower the number, the brighter the object. The Sun is magnitude −26.7, while the Full Moon is −12.5. The brightest star, Sirius, is magnitude −1.46. Stars decrease in brightness as the number increases, with the typical lower limit of human visibility being between magnitude 6.5 and 7.0.

Mare: A term referring to a dark patch on the surface of the Moon (*plural* maria), meaning 'sea'.

Meridian: An imaginary line on the celestial sphere that connects north and south, passing through the zenith and nadir.

Messier catalogue: A catalogue of non-cometary objects originally started by French astronomer Charles Messier. It features celestial objects that can look like comets to the unaided eye but are not, such as nebula, star clusters and galaxies.

Meteor: The visible streak of light made by small space debris burning as they fall through the Earth's atmosphere, commonly known as 'shooting stars' or 'falling stars'.

Meteorite: Any space debris (meteoroid) that reaches the surface of the Earth.

Meteoroid: Any natural debris in space that is smaller than 10 metres in diameter.

Nadir: The point directly below an observer on the celestial sphere.

Neap tide: Scientific term for tides that occur when the Moon is at a 90-degree angle between the Earth and Sun, causing the lowest difference between high and low tide. This occurs during First and Last Quarter Moons.

Nebula: A region of gas and dust that appears as either a bright patch (emission or reflection nebula) or

dark patch (absorption nebula) in the night sky.

Neutron star: The dense core of a supergiant star that collapsed and exploded in a supernova. These stars are the densest stellar objects in the Universe and are about 10 kilometres in diameter.

New Moon: The phase of the Moon where its fully illuminated side is facing away from the Earth. A New Moon is essentially invisible to observers and is near the Sun in the sky, rising at dawn and setting at dusk.

Nova: A term meaning 'new star', caused by thermonuclear explosions on white-dwarf stars in binary systems that accrete matter from their companion star until they reach a critical density (*plural* novas or novae). Novas appear suddenly then gradually fade over time, ranging from weeks to months.

Nutation: The small periodic change in the Earth's axis of rotation occurring on timescales of 18.6 years. This slightly alters the apparent position of the Earth's celestial poles over time.

Partial eclipse: When an observer sees part of the Sun covered by the Moon, or the Moon passing near the full shadow of the Earth, but not directly in it.

Perigee: The point in the orbit of the Moon when it is closest to the Earth.

Perihelion: The point in the orbit of the Earth when it is closest to the Sun. Perihelion occurs each year in early January, about two weeks after the December solstice.

Pole star: The star closest to the north or south celestial pole. For the northern hemisphere, this is currently Polaris (Alpha Ursae Minoris). There is currently not a bright south pole star. The closest visible south pole star is Sigma Octantis, a faint magnitude 5.47 star that is 1 degree from the SCP.

Precession: The wobble of the Earth's axis as orbits the Sun, for which it traces out a large circle with respect to the background stars every 26,000 years. This affects the direction of the celestial poles relative to the background stars.

Proper motion: The change in a star's position in two dimensions as seen from Earth as it orbits the centre of the Milky Way galaxy. Changes in position are measured with respect to right ascension and declination.

Red-giant star: A bright star in the dying stages of its evolution. It is of intermediate to low mass (between 0.3 and 8 times the mass of our Sun) that has expanded, becoming redder as it cools.

Refraction index: A term referring to the value by which the direction of light is changed as it passes through a new medium of different density.

Resonance: A state of relative balance between the orbits of two planets as they orbit the Sun, causing their orbital periods to be related by a ratio of small integers.

Retrograde motion: The apparent backward west-to-east motion of a planet each night relative to the background stars. This is caused when an inferior planet (those closer to the Sun than the Earth) overtakes, or a superior planet (those further from the Sun than the Earth) is overtaken by, the Earth as it orbits the Sun.

Right ascension: The projection of the Earth's longitude into space. Lines of right ascension run from celestial pole to celestial pole, measured in hours, minutes and seconds of time.

Saros cycle: A period of 223 synodic months, or approximately 6585.3211 days (18.029 years), that can be used to predict eclipses. Following an eclipse, a saros cycle is when the Earth, Sun and Moon return to approximately the same relative geometry.

Seeing conditions: A term used by astronomers to refer to atmospheric conditions and how well one can 'see' the stars through a telescope. The best seeing conditions are in places where the air is dry, cold, still, dark and thin (high elevation).

Scintillation: The twinkling of celestial objects (rapid changes in their brightness) caused by turbulence in the Earth's atmosphere.

Solstice: The point on the horizon where the rising or setting Sun reaches its northernmost or southernmost position. In the southern hemisphere, the summer solstice rises and sets as its southernmost azimuth on or around 21 December and the northernmost azimuth on or around 21 June. This is the opposite for the northern hemisphere.

Spring tides: Tides that occur when the Sun, Earth and Moon are in rough alignment, causing the largest change between high and low tides. This occurs during New and Full Moons.

Sunspot: A temporary dark patch on the surface of the Sun.

Supermoon: A term used when the Moon is closest to the Earth (at perigee) and has a larger angular diameter, making it appear bigger in the sky.

Supernova: The powerful and luminous explosion of a star, formed from the core collapse of a massive star or runaway nuclear fusion on a white-dwarf star (*plural* supernovas or supernovae). Supernovas are more energetic than novas and can outshine an entire galaxy before fading from visibility weeks to months later.

Synodic period: The time it takes for a celestial object to return to the same position in the sky.

Syzygy: The perfect alignment of three astronomical bodies, such as the Sun, Earth and Moon. Eclipses occur when these three bodies are in syzygy.

Total eclipse: For solar eclipses, this occurs when the Moon completely covers the Sun. For a lunar eclipse, this occurs when the Moon falls completely within the shadow of the Earth.

Variable star: A star whose brightness changes over time. This change can be intrinsic (within the star itself, such as pulsating stars or those with their own ‘sunspots’) or extrinsic (outside the star), such as eclipsing binary stars.

Waning Moon: The duration of lunation when we see less of the Moon’s illuminated side each day.

Waxing Moon: The duration of lunation when we see more of the Moon’s illuminated side each day.

White-dwarf star: The remnant core of a previously larger star that died but was not massive enough to explode in a supernova. They are very dense and about the size of the Earth.

Zenith: The point directly above an observer on the top of the celestial dome, with an altitude of 90 degrees.

Zodiac: The area on the celestial sphere 9 degrees either side of the ecliptic. The pathways of the Sun, Moon and all the planets are within this band of the celestial dome. Also a reference to constellations through which the ecliptic passes.

Zodiacal light: A glow caused by sunlight reflecting off dust in the plane of the Solar System. The light reduces in brightness further away from the Sun, appearing as a tall, narrow, triangle-shaped tower of diffuse white light.

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Prologue

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